



US Army Corps
of Engineers

TECHNICAL REPORT CERC-85-8

BREAKWATER REHABILITATION STUDY, CRESCENT CITY HARBOR, CALIFORNIA

Coastal Model Investigation

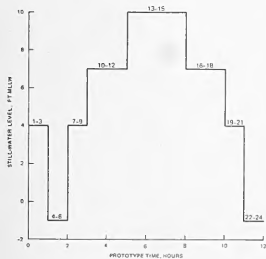
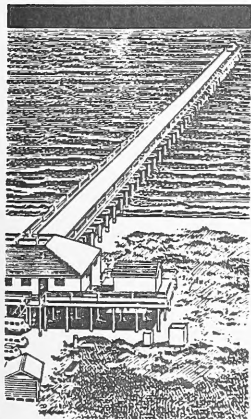
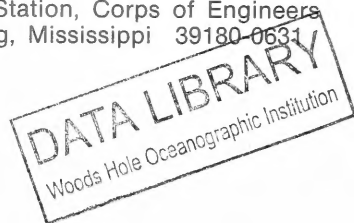
by

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Coastal Engineering Research Center

DEPARTMENT OF THE ARMY

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NOTES: NUMBERS INDICATE HYDROGRAPH
STEP NUMBER
TEST CONDITIONS FOR EACH
STEP ARE GIVEN IN TABLE 2.

HYDROGRAPH A



November 1985

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for

US Army Engineer District, Los Angeles
Los Angeles, California 90053

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CERC-85-8

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report CERC-85-8	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) BREAKWATER REHABILITATION STUDY, CRESCENT CITY HARBOR, CALIFORNIA; Coastal Model Investigation		5. TYPE OF REPORT & PERIOD COVERED Final report
7. AUTHOR(s) R. Clay Baumgartner Robert D. Carver D. Donald Davidson		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Coastal Engineering Research Center PO Box 631, Vicksburg, Mississippi 39180-0631		8. CONTRACT OR GRANT NUMBER(s) Intra-Army Order No. REV 84-13 dated 23 Jan 1984
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Engineer District, Los Angeles Los Angeles, California 90053		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (If different from Controlling Office)		12. REPORT DATE November 1985
		13. NUMBER OF PAGES 307
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Breakwaters (LC) Harbors--Maintenance and repair (LC) Harbors--California--Crescent City (LC) Crescent City (Calif.)--Harbor (LC)		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) An undistorted scale hydraulic model study was conducted to develop an adequate repair plan for a section of the Crescent City breakwater which was armored with dolosse. The damaged area was to be repaired with 42-ton dolos. It was desired to quantify the number of armor units required, the optimum slope on which to place the dolosse, overall constructability, and methods of stabilizing the transition areas. Based on results of model tests, a combination of trenching and buttressing with 25-ton armor stone is a constructable method of stabilizing the transition area.		

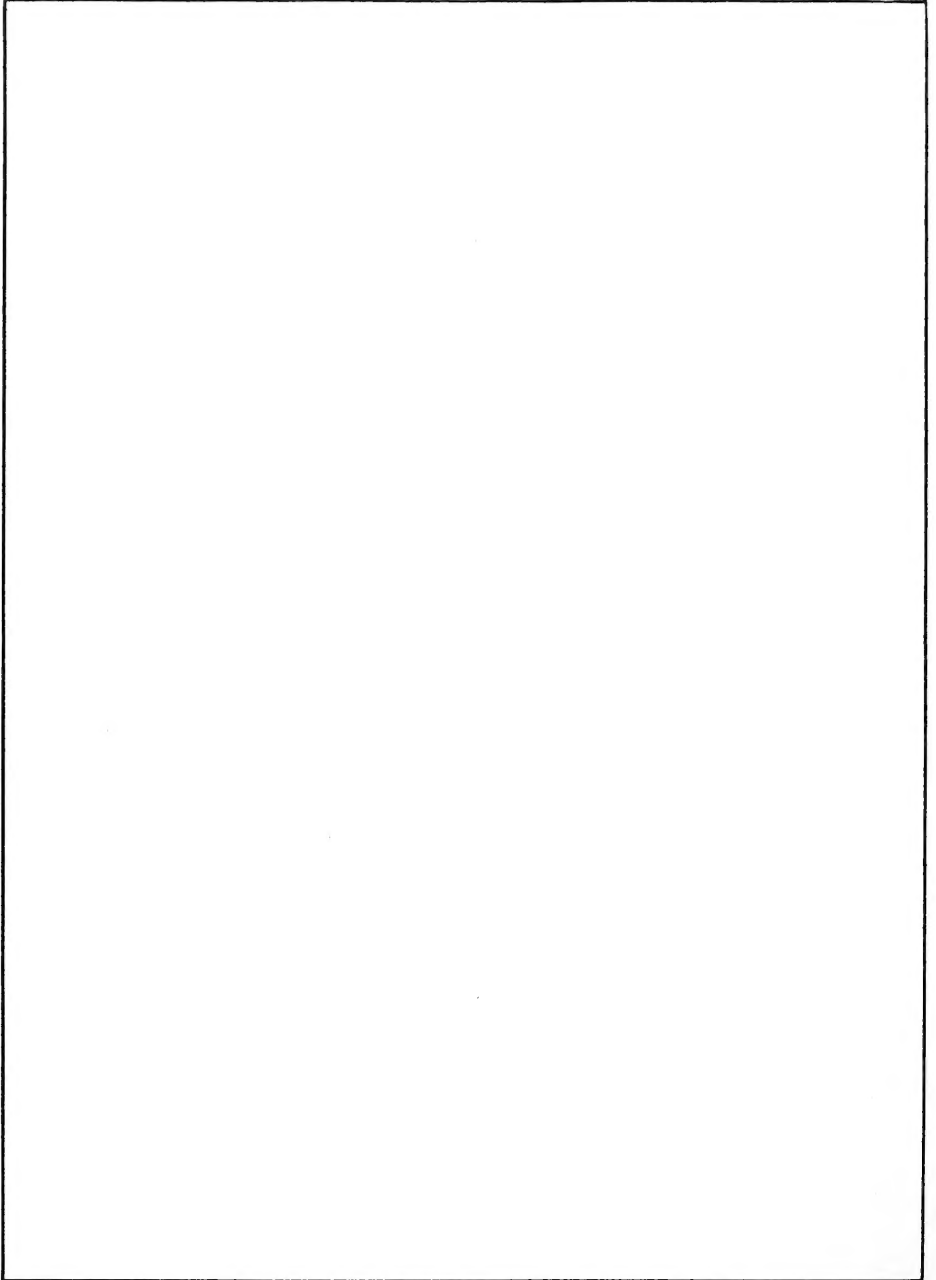
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PREFACE

The model investigation described herein was requested by the US Army Engineer District, Los Angeles (SPL), in a letter to the US Army Engineer Waterways Experiment Station (WES) dated 12 December 1983. Funding authorization from SPL was granted in SPL Intra-Army Order No. Rev 84-13, dated 23 January 1984.

Model tests were conducted at WES during the period July 1984 to March 1985 under the general direction of Dr. R. W. Whalin, former Chief, Coastal Engineering Research Center; Mr. C. E. Chatham, Chief, Wave Dynamics Division; and Mr. D. D. Davidson, Chief, Wave Research Branch. Tests were conducted by Messrs. R. D. Carver and R. C. Baumgartner, Research Hydraulic Engineers, and Mr. C. R. Herrington and Mrs. B. J. Wright, Engineering Technicians. Mr. Herrington served as Lead Technician under the immediate supervision of Messrs. Carver and Baumgartner. The wave refraction/diffraction/shoaling study was performed by Dr. L. Z. Hales, Research Hydraulic Engineer, Coastal Processes Branch. This report was prepared by Messrs. Baumgartner, Carver, and Davidson.

During the study Messrs. Tom Kendall, Bill Angeloni, Jay Soper, and John Azeveda of SPN; Messrs. Paul Berger, Tad Nazinski, Dee Gonzales, and Mrs. Laurie Ruh-Hanson of SPL; and Messrs. Bob Edmisten and Hugh Converse of US Army Engineer Division, South Pacific, visited WES to observe model operation and provide input relative to the course of testing.

Director of WES during the preparation of this report was COL Allen F. Grum, USA; Dr. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic yards	7.645549	cubic metres
feet	0.3048	metres
inches	2.54	centimetres
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
tons (2,000 pounds mass)	907.1847	kilograms

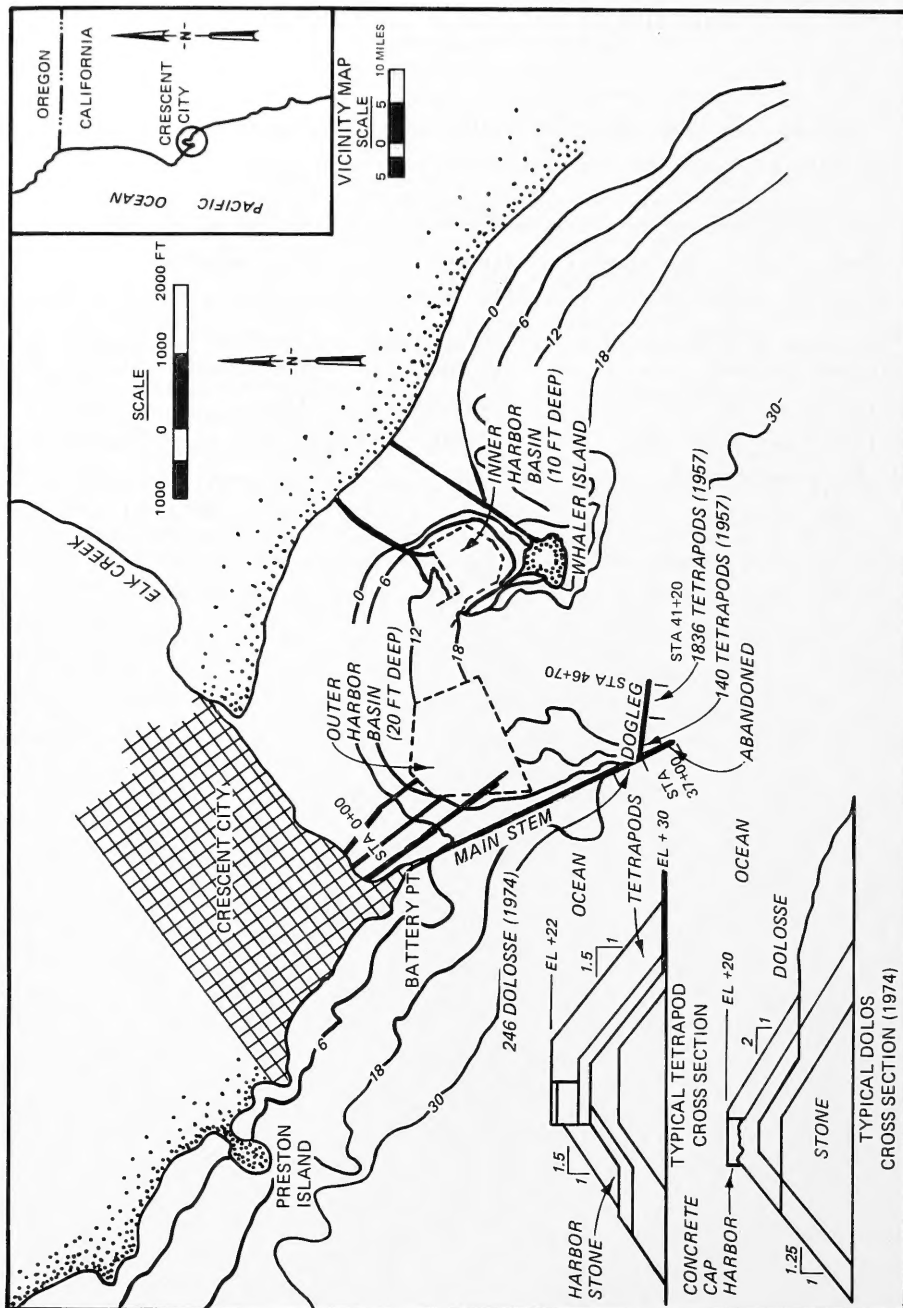


Figure 1. Vicinity and location map, Crescent City breakwater

BREAKWATER REHABILITATION STUDY, CRESCENT
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PART I: INTRODUCTION

The Prototype

1. Crescent City Harbor, Calif., is located on the Pacific Coast approximately 17 miles* south of the Oregon-California border (Figure 1). The existing outer breakwater is 4,670-ft long, the main stem is 3,670-ft long, and the easterly extension (dogleg) of the breakwater is 1,000-ft long. Original project plans intended for the main stem of the breakwater to extend out to an area called Round Rock. However, beyond sta 37+00 the main stem of the original breakwater sustained severe damage and was reconstructed on two occasions. Finally, this portion of the main stem was abandoned and the present 1,000-ft-long easterly dogleg was added.

2. Two-dimensional (2-D) stability tests were conducted on the tetrapod armor designs proposed for the trunk portion of the 1,000-ft dogleg (Hudson and Jackson 1955, 1956). In 1957, 1,836 25-ton unreinforced tetrapods were placed on the sea-side slope from sta 41+20 to the end of the dogleg (sta 46+70), and 140 25-ton unreinforced tetrapods were stockpiled on the sea-side slope of the first 200 ft of the dogleg, adjacent to the main stem (sta 37+00 to 39+00). As of 1975, approximately half of the tetrapods placed between sta 37+00 and 39+00 had broken because of severe wave action at the elbow. In 1974 the stone-armored section, close to sta 37+00 shoreward to about sta 35+00, had deteriorated to the extent that 246 40- to 42-ton unreinforced dolosse were placed on the sea-side slope of the last 230 ft of the breakwater's main stem (sta 34+70 to 37+00). Various portions of the breakwater, including the deteriorated tetrapod area (sta 37+00 to 39+00), were also repaired with armor stone in 1979.

3. Sea-side slopes of the outer 230 ft of the main stem (sta 34+70

* A table of factors for converting Non-SI units of measurement to SI (metric) units is presented on page 3.

to 37+00) have sustained damage during recent years. Present plans envision repairing these areas of the breakwater with 42-ton reinforced dolosse.

Purpose and Approach of Model Study

4. The purpose of this study was to develop a technically sound repair plan based on results of three-dimensional (3-D) stability tests. More specifically, it was desired to quantify such variables as the number of armor units required, the optimum slope on which to place the dolosse, overall constructability, and methods of stabilization of the transition areas.

PART II: THE MODEL

Model-Prototype Scale Relationships

5. Tests were conducted at a geometrically undistorted scale of 1:57.5, model to prototype. Scale selection was determined by the following conditions: (a) absolute size of model breakwater sections necessary to ensure the preclusion of stability scale effects (Hudson 1975), (b) capabilities of an available wave generator, and (c) the depth of water at the toe of the breakwater. Based on Froude's model law (Stevens et al. 1942) and the linear scale of 1:57.5, the following model-prototype relations were derived. Dimensions are in terms of length (L) and time (T).

<u>Characteristic</u>	<u>Dimension</u>	<u>Model-Prototype Scale Relation</u>
Length	L	$L_r = 1:57.5$
Area	L^2	$A_r = L_r^2 = 1:3,306$
Volume	L^3	$V_r = L_r^3 = 1:190,109$
Time	T	$T_r = L_r^{1/2} = 1:7.58$

6. The specific weight of water used in the model was assumed to be 62.4 pcf and that of seawater to be 64.0 pcf; specific weights of model breakwater construction materials were not identical with their prototype counterparts. The variables are related using the following transference equation:

$$\frac{(W_a)_m}{(W_a)_p} = \frac{(\gamma_a)_m}{(\gamma_a)_p} \left(\frac{L_m}{L_p} \right)^3 \left[\frac{(S_a)_p - 1}{(S_a)_m - 1} \right]^3$$

where

W_a = weight of an individual armor unit, lb

subscripts m and p = model and prototype quantities, respectively

γ_a = specific weight of an individual armor unit, pcf

L_m/L_p = linear scale of model

S_a = specific gravity of an individual armor unit relative to water in which the breakwater is constructed (i.e., $S_a = \gamma_a/\gamma_w$, where γ_w is the specific weight of water, pcf)

Modeling Local Bathymetry

7. Local prototype bathymetry was represented by a 1V-on-35H slope, starting at the toe of the existing breakwater and extending seaward for a simulated prototype distance of 425 ft (7.4-ft model), followed by slopes of 1V on 85H and 1V on 20H with simulated prototype distances of 805 ft (14-ft model) and 725 ft (12.6-ft model), respectively (Figure 2). Shoreward of the existing breakwater toe the bottom was assumed to be flat, with a simulated prototype elevation of -29 ft mean lower low water (mllw).

Selection of Test Conditions

8. Surge levels from the prototype data indicated that the extreme range of water levels that could be expected at the breakwater during its design life was -1 to +10 ft mllw. Four water levels were selected for testing. They included simulated prototype surges of -1, +4, +7, and +10 ft mllw.

9. For a given wave period and water depth, the most detrimental breaking wave (i.e., the most damaging wave) was determined by increasing the stroke adjustment on the wave generator in small increments and observing which wave produced the most severe breaking wave condition on the structure. Wave heights of lower amplitude did not form the critical breaking wave, and wave heights of larger amplitude would break seaward of the test section and dissipate their energy so that they were less damaging than the critically tuned wave.

10. Initially, test sections were subjected to an abbreviated hydrograph (Table 1 and Plate 1). Only those plans which showed an acceptable stability response for the abbreviated hydrograph were tested with the full-length hydrographs. Two typical storm-surge hydrographs, representative of conditions along the Northern California Coast, were furnished by the sponsor. Test conditions for these hydrographs are listed in Tables 2 and 3. Plates 2 and 3 graphically depict surge level as a function of time.

11. The breakwater is generally exposed to waves clockwise from south to west. From the refraction, diffraction, and shoaling report (Hales 1985), the most severe depth-limited breaking waves that can reach the structure occur from the southern to the southwestern direction and intersect the main stem of the breakwater at approximately 67.5 and 90 deg, respectively.

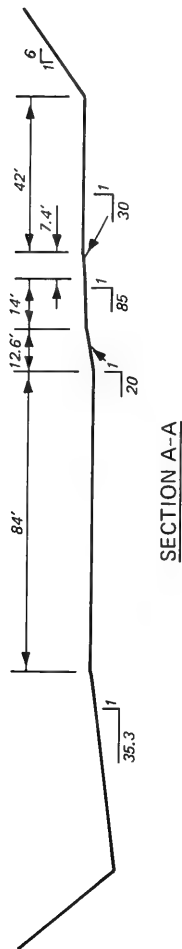
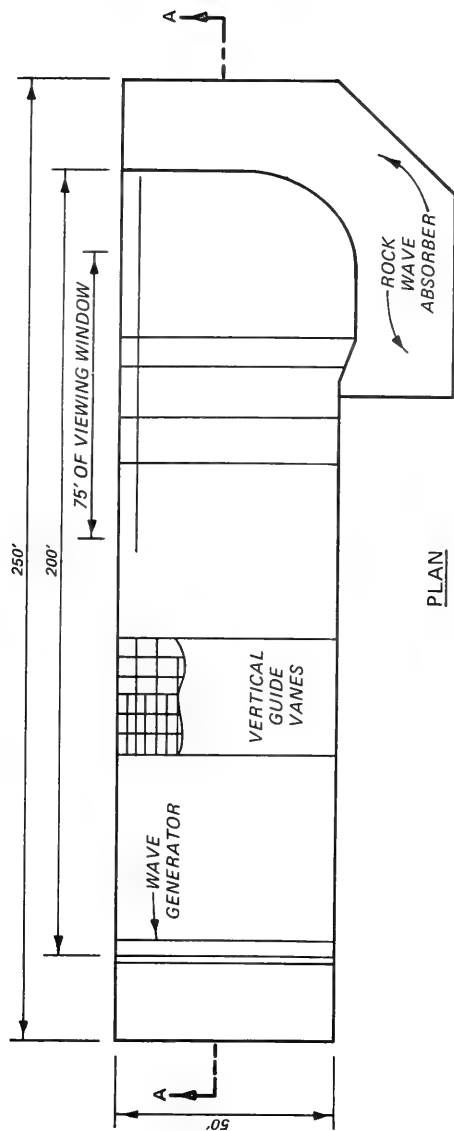


Figure 2. Wave basin geometry

Therefore these two angles were selected for testing (see Plate 4).

Design of Model Breakwater

12. Plates 4 and 5 and Photos 1-6 show the existing structure as represented in the model. The breakwater was reproduced from sta 31+25 to 40+00, with dolos coverage from just below mllw up to the crest of the breakwater between sta 34+70 and 37+00. Dolos used in the model represented 42-ton units in the prototype. Several different configurations, or plans, were tested in an attempt to arrive at a feasible design for the dolos rehabilitation area. These plans are described in Part III.

Model Construction

13. The model breakwater was constructed to reproduce, as closely as possible, results of the usual methods of constructing prototype breakwaters. The core material was dampened as it was dumped by bucket or shovel into the flume and then was compacted with hand trowels to simulate natural consolidation resulting from wave action during construction of the prototype structure. Once the core material was in place, it was sprayed with a low-velocity water hose to ensure adequate compaction of the material. The underlayer stone then was added by shovel and smoothed to grade by hand or with trowels. No excessive pressure of compaction was applied during placement of the underlayer stone. Except for the toe area of the dolos, armor units used in the cover layers were placed in a random manner corresponding to work performed by a general coastal contractor (i.e., they were individually placed but were laid down without special orientation or fitting). Special placement was used for the toe of the rehabilitated dolosse units (i.e., the dolos were placed with their shanks parallel to the slope of the breakwater and their vertical fluke downslope away from the crest), or in the case of transition areas, the vertical fluke faced outward from the body of the dolos section. Any deviation from this type of placement is described in the individual test plans. After each test, the armor units were removed from the breakwater, all of the underlayer stones were replaced to the grade of the original test section, and the armor was replaced.

14. The model was built on a baseplate made of 16-gage sheet metal which allowed the breakwater to be rotated so different angles of wave attack could be tested. Templates made from 20-gage sheet metal were riveted to the baseplate to aid in construction. The templates extended through only the core material in the model breakwater and had 1-in.-diam holes drilled to make them porous. Templates were necessarily avoided in the first underlayer and primary armor because they would interface with the natural stability of the material. Elevations in the first underlayer and primary armor were controlled by measurements with an engineer's level.

15. The model was constructed by using the cross sections (shown in Plate 5) and the considerations discussed in the following paragraphs.

Main stem of breakwater

16. The average stone size used to protect the exposed shoreward section of the model (sta 31+25 to 34+70) was one layer of 25-ton stone placed over one layer of 12-ton stone, all of which was on a compound slope of 1V to 4H and 1V to 1.5H (Section A-A, Plate 5).

17. The model cap section was geometrically similar to the prototype concrete cap, but was made of wood that was bolted to the baseplate to assure no movement.

Existing dolos area

18. The stone material under and seaward of the existing dolosse (Section B-B, Plate 5) consisted of an average stone size of 12 tons.

19. Positioning of the existing model dolosse was controlled by using aerial photographs in order to reproduce the existing prototype section as accurately as possible.

Breakwater extension

20. The existing armor protection of the breakwater extension (sta 37+00 to 40+00) consists of one layer of 25-ton stone placed over one layer of 12-ton stone on a 1V-to-4H slope (Section C-C, Plate 5).

21. The shoal material seaward of the breakwater, representing remnants of the old deteriorated extension toward Round Rock, consists of a mixture of 12- to 25-ton stone.

22. One hundred and forty tetrapods, including 70 broken ones, were added randomly in the area from sta 37+00 to 39+00 to represent the deteriorated tetrapod section.

Method of Reporting Damage

23. The following list of adjectives, in order of increasing severity, was used for recording model observations and reporting test results for each test section: (a) slight, (b) minor, (c) moderate, (d) significant, (e) major, and (f) extensive. Slight and minor were used to describe acceptable results, moderate described borderline acceptability, while significant to extensive described unacceptable conditions of increasing severity. Use of these adjectives allows for some quantification of the severity of resulting damage incurred by the breakwater's primary cover-layer units. By using the descriptive adjectives and the before- and after-test photographs, comparisons can be made between alternative test sections.

PART III: TESTS AND RESULTS

Test Facilities and Equipment

24. All tests were conducted in an L-shaped wave basin which is 250 ft long, 50 and 80 ft wide at the top and bottom of the L, respectively, and 4.5 ft deep (Figure 2). The test facility was equipped with a flap-type generator which is capable of producing monochromatic waves of various periods and heights.

Calibration of Test Facility

25. Normal procedure at the US Army Engineer Waterways Experiment Station (WES) is to calibrate the wave facility without the breakwater structure present. This is the most accurate means of calibrating, and is analogous to the prototype conditions for which the measured and/or hindcast wave data were determined. Electrical resistance-type wave gages were positioned in the wave flume at a point that would coincide with the toe of the proposed breakwater section, and the wave generator was calibrated for various selected wave conditions.

Test Procedure

26. A typical stability test consisted of subjecting the test section to a series of waves from a previously determined hydrograph. The test section was subjected to wave attack in approximately 45-sec intervals, between which the wave generator was stopped and the waves were allowed to decay to zero height. This procedure was necessary to prevent the structure from being subjected to an undefined wave system created by reflections from the breakwater and wave generator. Newly built test sections were subjected to a short duration (five or six 45-sec intervals) of shakedown by using a wave equal in height to about one-half of the estimated no-damage wave. This procedure provided a means of allowing consolidation and armor unit seating that would normally occur during prototype construction.

Stability Tests

27. Thirty plans were tested for 90-deg wave attack (wave direction 1), and two of these were also tested at a 67.5-deg angle (wave direction 2). The sponsor initially stated that the existing underwater slopes would not be dressed, nor would material be removed to make better seating for the dolos overlay and/or toe. (It was planned to lay the dolosse on whatever slope and material presently exist.) This limited the initial design alternatives to special toe placement, varying geometry, and area of coverage (this alternative was somewhat limited due to cost). After the initial design alternatives were found to be inadequate, trenching and buttressing were tried with improved results. The abbreviated hydrograph (Table 1) was used for initial testing, and damage to the test structures was determined by observation. Details of the plans tested and general results follow.

Development of stable sections for a 90-deg angle of wave attack

28. Plan 1 (Plate 6 and Photos 7-10) was constructed with the toe of the rehabilitation dolos 98 ft from the outer edge of the cap. A total of 177 dolosse were used. Damage to the structure was severe, and the entire toe area was displaced. Damage originated at the toe, and as the toe units were displaced the units upslope unraveled. The dolosse flukes extended above the still water level (swl) at the toe of the rehabilitation area for all water depths. Therefore, it was decided that the toe of the dolos would have to be placed in deeper water to remove it from the high wave energy region around the swl. Photos 11-14 show the structure after testing.

29. Plan 2 (Plate 7 and Photos 15-18) was constructed with the toe of the rehabilitation dolos 160 ft from the outer edge of the cap. A total of 381 dolosse were used. The toe units in the left (shoreward) transition and central areas were stable; however, there was severe damage to the toe units in the right (seaward) transition area. The damage was occurring at the swl, and as the water depth was increased the damaged area moved upslope. Because of the geometry of the breakwater (i.e., the dogleg), wave energy is concentrated in this area and problems were expected in this region. Photos 19-21 show the structure after testing.

30. Plan 2A (Plate 7 and Photos 22-23) was the same as Plan 2, except that the toe units in the seaward transition area were placed with their

vertical flukes outward rather than downslope. There was no improvement in dolos stability over Plan 2. Photos 24-26 show the structure after testing.

31. Plan 2B (Plate 7 and Photos 27-28) was the same as Plan 2A, except that special placement was used for the toe units in the seaward transition area, i.e., the toe units in the second layer were placed to ensure double locking with the toe units in the bottom layer (see Photo 29). This plan performed less satisfactorily than Plan 2A in that failure was not gradual; the entire toe area failed as one unit. Tests conducted to date indicated that additional dolosse would be required to move the seaward transition further out the extension into a region where the wave action would probably be less severe. Photos 30-32 show the structure after testing.

32. Plan 3 (Plate 8 and Photos 33-35) was constructed with the toe of the dolos rehabilitation units still 160 ft from the outside edge of the cap; however, for this plan the dolos extended further out the eastern extension to sta 38+00. A total of 576 dolosse were used in the rehabilitation area. The lower corner of the seaward transition area now rested on material in the shoal area, and the flukes of these toe units were exposed for swl's of -1 and +4 ft. Damage originated in this location for these water levels and became severe for the +7-ft swl. Although there was less damage than for previous plans, the damage was still too excessive for the plan to be acceptable. Photos 36-38 show the structure after testing.

33. Plan 3A (Plate 8 and Photos 39-41) was the same as Plan 3, except that in the lower seaward region of the dolos rehabilitation units a 50- by 110-ft area was constructed three layers thick. The total number of rehabilitation units used was 615. Damage still occurred at the lower toe area of the seaward transition where the toe units are exposed at the lower water levels. Plans 3 and 3A may have been improved by moving the lower toe units of the seaward transition into deeper water; however, the bottom profile in this area is virtually flat. Thus, distance from the cap to the toe would have been too great to make it a feasible alternative. Photos 42-44 show the structure after testing.

34. Plan 4 (Plate 9 and Photos 45-47) was constructed with the same dimensions as Plan 3, except the toe of the seaward transition of the rehabilitation units formed a line perpendicular to the main breakwater stem, with the upper corner starting at sta 38+00. A total of 525 dolosse were used in the rehabilitation area. This geometry was selected for testing

because the toe units of the seaward transition should have been subjected to minimum force components acting to push the units outward from the rest of the rehabilitation dolosse, for the 90-deg angle of wave attack. The seaward transition still suffered severe damage. Apparently, diffraction effects in this area of the breakwater caused significant forces on the dolosse.

Photos 48-50 show the structure after testing.

35. Plan 5 (Plate 10 and Photos 51-53) was the same as Plan 3, except that the seaward transition of the rehabilitation units extended out the eastern extension to sta 39+00. A total of 776 dolosse were placed in the rehabilitation area. The lower corner of the seaward transition still rested on material in the shoal area, leaving the flukes of toe units exposed at swl's of -1 and +4 ft; these toe units were subjected to considerable wave energy even though they had been placed out to sta 39+00. Extensive damage occurred in the area of the seaward transition. Photos 54-56 show the structure after testing.

36. Plan 6 (Plate 11 and Photos 57-59) was constructed with the rehabilitation units ending at sta 37+00. A total of 303 rehabilitation dolosse were placed. This plan showed the most promise of any tested to date, as only six rehabilitation dolosse were displaced in the seaward transition. Damage occurred near the swl, and as the water depth was increased the damaged area moved upslope. At this time it was determined that a trench might stabilize toe units in the seaward transition. Note, existing dolosse that extended past the end of the cap received no protection from the rehabilitation units; these existing units were displaced during testing. Photos 60-62 show the structure after testing.

37. Plan 7 (Plate 11 and Photos 63-65) was the same as Plan 6, except that a trench was excavated starting at the toe of the existing dolosse (0.0 ft mllw) and ending a distance 100 ft from the outside of the cap at -11.0 ft mllw. The trench followed a line which was perpendicular to the main breakwater stem and intersected at cap at sta 37+00. The trench was about 5 ft deep, i.e., deep enough that when the vertical fluke of a dolosse was placed vertically in the trench, it was securely supported from slipping. Toe units in the seaward transition of Plan 7 were placed as in Plan 6, except some of the units rested in the trench. Dolosse along the seaward transition remained stable during testing. The structure was rebuilt and the test repeated. Results for the repeat tests were the same except three units were

displaced at the shoreward transition; the movement occurred during the first wave cycle and the shoreward transition units remained stable for the rest of the testing. As in Plan 6, existing dolosse that extended past the cap were displaced, and in Plan 7 damage to the existing dolosse began to progress shoreward from the end of the cap. Photos 66-68 and 69-71 show the results of the initial and repeat tests, respectively.

38. Plan 8 (Plate 12 and Photos 72-74) was tested in an effort to find a section that would encompass and provide protection to existing dolosse seaward of sta 37+00. A total of 334 rehabilitation dolosse were placed. A trench was excavated along part of the seaward transition to stabilize the toe and is shown in Plate 12. The existing dolosse seaward of the cap end still sustained damage; in addition, three rehabilitation units were displaced along the toe of the seaward transition. Photos 75-77 show the structure after testing.

39. Plan 9 (Plate 13 and Photos 78-80) was constructed with the 42-ton rehabilitation units encircling the existing dolosse in a continuing effort to provide protection for the existing dolosse seaward of the cap. A total of 381 rehabilitation dolosse were placed. Once again, a trench was excavated along part of the seaward transition and is shown in Plate 13. Although this plan did protect the existing dolosse, the seaward transition of the rehabilitation units sustained damage. Photos 81-83 show the structure after testing.

40. Plan 10 (Plate 14 Photos 84-86) was based on the photographs taken of the prototype in 1984; the existing dolosse section in the model was modified to more closely represent the 1984 conditions. A new geometry of the seaward transition was tried along with another excavated trench as shown in Plate 14. A total of 348 42-ton rehabilitation units were used. Plan 10 sustained an unacceptable amount of damage for the abbreviated hydrograph. Photos 87-89 show the structure after testing.

41. Plan 11 (Plate 15 and Photos 90-92) was similar to Plan 10, except the area of coverage was increased. A total of 384 42-ton rehabilitation units were placed. The excavated trench is shown in Plate 15. This plan performed satisfactorily for the abbreviated hydrograph. Photos 93-95 show the structure after testing. It was thought by visiting sponsor representatives that the toe placement in the transition areas of the model may have been more precise than what could be obtained in the prototype; thus, Plan 11 was repeated with the vertical leg of the toe units still placed seaward but in a

more random fashion. The units along the seaward transition sustained considerable damage for the repeat test. Photos 96-98 show the structure after repeat testing. The repeat test indicated that toe placement is critical in the stability of the structure.

42. Plan 12 (Plate 16 and Photos 99-101) was constructed with two rows of 58-ton dolosse along the seaward transition of the elbow; the 58-ton units along the toe were randomly placed. It was hoped that the heavier units would stabilize this area without trenching. A total of 46 58-ton and 319 42-ton rehabilitation dolosse were placed. The seaward transition sustained severe damage during testing. Photos 102-104 show the structure after testing.

43. Plan 13 (Plate 16 and Photos 105-107) was similar to Plan 12, except some additional 58-ton dolosse were placed. Also, special placement was used for the toe units. A total of 65 58-ton and 313 42-ton rehabilitation units were placed. The seaward transition still sustained damage during testing. Photos 108-110 show the structure after testing.

44. Plan 14 (Plate 16 and Photos 111-113) was similar to Plan 13, except a trench was excavated along part of the seaward transition. A total of 61 58-ton and 312 42-ton rehabilitation units were placed. Again the seaward transition sustained damage during testing. Photos 114-116 show the structure after testing. At this time it was decided that the larger units exhibited more surface area for the waves to work on and were not a feasible alternative unless higher density concrete was used, which in effect, would increase the weight without increasing the surface area. Since high-density model units were not available to show this effect and the time limitation prevented making additional model units, future efforts concentrated on finding a stable section using the 42-ton dolosse.

45. Plan 15 (Plate 17 and Photos 117-119) was constructed with a trench approximately one dolos wide and about 5 ft (one-stone-diameter) deep. After the units were placed in the trench, the voids between units in the trench were backfilled with material left over from the excavation. Special placement was used for the toe units. The total number of 42-ton rehabilitation units was 373. Again damage exceeded acceptable limits. Although much of the backfill material was scoured out during testing, placement of the backfill material did improve the stability of the seaward transition. Photos 120-122 show the structure after testing.

46. Plan 16 (Plate 18 and Photos 123-125) was similar to Plan 15,

except the area of coverage was increased. The waves tended to break on the structure and then rush out the dogleg, and it was hoped additional units in this area would dissipate enough of the wave energy to protect the toe units in the seaward transition area of the elbow. A total of 406 42-ton rehabilitation dolosse were used. Damage of the seaward transition was still unacceptable. Photos 126-128 show the structure after testing.

47. Plan 17 (Plate 19 and Photos 129-131) was similar to Plan 15, except the area of coverage again was increased. A total of 443 42-ton rehabilitation dolosse were placed. This plan performed satisfactorily for the abbreviated hydrograph. Photos 132-134 show the structure after testing.

48. Plan 18 (Plate 20 and Photos 135-137) was a refinement of Plan 17. The total number of 42-ton rehabilitation dolosse was reduced to 398 by removing units near the crown of the dogleg. Plan 18 performed satisfactorily for the abbreviated hydrograph; results are shown in Photos 138-140. The test section was rebuilt and again subjected to the abbreviated hydrograph. A total of 394 rehabilitation units were used and Photos 141-143 show the structure after the repeat test. The repeat test sustained more damage than the original, but the amount of movement was considered acceptable. Plan 18 was rebuilt and subjected to a full-length storm (Hydrograph A, Table 2). A total of 410 rehabilitation dolosse were placed. Plan 18 performed satisfactorily for the full-length storm. Photos 144-146 show the structure after testing. Concern arose as to the prototype constructability of the toe trench; therefore, it was decided to develop alternative plans.

49. Plan 19 (Plate 21 and Photos 147-149) was similar to Plan 18, except a rock buttress was placed around the outer perimeter of the seaward transition. Also three concrete blocks were added to represent remnants of the deteriorated cap of the old breakwater extension. No trenching was used for this plan, and special placement was used for the dolos toe units. The rock buttress was placed before the rehabilitation dolosse and consisted of 25-ton armor stone two layers deep and approximately 35 ft wide. The total number of armor stones added was 188; assuming a specific weight of 170 pcf and a porosity factor of 0.63, the total weight of stone used was 4,700 tons with a volume of approximately 3,250 cu yd. A total of 408 42-ton rehabilitation dolosse were used. Plan 19 was subjected to the abbreviated hydrograph. The rock buttress sloughed off in the lower region of the seaward transition and was undamaged near the crown of the dogleg where the stone was protected

by dolosse. However, the armor stone of the barricade in the central region of the seaward transition (in the range of swls used for testing) where the wave energy was most severe were completely washed out. The rock buttress did afford the dolosse some protection but the performance of this plan was considered marginal. Although only one dolos was actually displaced, there was a separation of dolosse near the seaward transition toe. These units probably would have been displaced during a longer storm. Photos 150-153 show the structure after testing.

50. Plan 20 (Plate 22 and Photos 154-156) had about the same area of coverage as Plan 18; however, 74 rehabilitation dolosse were removed and replaced with 82 37-ton tetrapods (37-ton tetrapods were used since this was the model size tetrapod available nearest to the 42-ton dolos size). The tetrapods were placed in one layer. It was thought that the tetrapods might be a more appropriate shape for interfacing the existing stone. A total of 334 42-ton dolosse were used. The tetrapods suffered extensive damage. There was minimum movement of the dolosse during the abbreviated hydrograph, but since they had lost the protection afforded by the tetrapods it is likely damage would have progressed to this area for a longer duration storm. Photos 157-159 show the structure after testing.

51. Plan 21 (Plate 23 and Photos 160-162) was similar to Plan 20, except more dolosse were replaced with tetrapods and the tetrapods were placed in two layers. A total of 304 42-ton rehabilitation dolosse and 116 37-ton tetrapods were used. The tetrapods sustained severe damage; damage progressed to the dolosse. Photos 163-165 show the structure after testing. Using tetrapods to stabilize the seaward transition was found to be unfeasible.

52. Plan 22 (Plate 24 and Photos 166-168) was similar to Plan 18, except that dolos toe units extended along a line which intersected with one of the concrete block remnants from the earlier breakwater extension. It was hoped the concrete block would act as a buttress for the dolosse. No trenching or other buttressing was used. The toe units of the rehabilitation dolosse were specially placed. A total of 445 42-ton rehabilitation dolosse were used. Although only four dolosse were displaced while testing with the abbreviated hydrograph, performance of the plan was considered marginal. There was a separation of toe units along the lower section of the seaward transition; these units probably would have been displaced for a longer duration storm. The concrete block did provide some protection to

the dolosse near it. Photos 169-171 show the structure after testing.

53. Plan 23 (Plate 25 and Photos 172-174) was similar to Plan 22, except coverage was reduced near the crown of the dogleg where dolosse were not needed and coverage was increased along the lower part of the seaward transition toe to provide additional protection in this area. A total of 484 42-ton rehabilitation dolosse were placed. Damage was severe in the seaward transition area for the abbreviated hydrograph. Photos 175-177 show the structure after testing.

54. Plan 24 (Plate 26 and Photos 178-180) was similar to Plan 19, except that the 25-ton armor stone used as a buttress extended back to the concrete block remnants. The buttress again was placed before the rehabilitation dolosse and consisted of 25-ton armor stone two layers deep. The total number of armor stones added was 278 with a total weight of 6,950 tons and a volume of approximately 4,810 cu yd. A total of 387 42-ton dolosse were placed and the test section was subjected to the abbreviated hydrograph. The rock buttress sloughed off during testing, as in Plan 19. However, the armor stone did remain in place long enough to protect the dolosse from displacement. Photos 181-183 show the structure after testing. Plan 24 was rebuilt and subjected to Hydrograph A to see if the dolosse would survive a storm of longer duration. A total of 410 42-ton dolosse and 293 25-ton armor stones were placed. The dolosse in the shoreward transition sustained some damage early in the testing, but this area stabilized and showed no movement during the rest of the hydrograph. The buttressing armor stone in the seaward transition again sloughed off and was scattered down the dogleg, with most of the damage occurring in the first half of the hydrograph. The dolosse in the seaward transition remained stable throughout the testing, except for a slight separation of dolosse in the lower seaward quadrant. Apparently the 25-ton armor stone remained in place long enough for the dolosse to become nested and interlock for the duration of Hydrograph A. At the end of Hydrograph A, a small amount of the 25-ton buttressing stone was left in the extreme lower and upper areas of the original buttressing, but most of the stone was scattered down the dogleg and/or was carried off the model section at sta 40+00. Photos 184-186 show the structure after testing with Hydrograph A. Although the dolosse remained virtually intact at this point, movement of the buttressing armor stone was excessive and could possibly have done structural harm to the tetrapod section further down the dogleg. Also, the dolos section was

left without buttressing for subsequent storm events. Based on these results and discussion with the Los Angeles District, it was decided that the test should be continued using Hydrograph B (Table 3). During testing of Hydrograph B, deterioration of the 25-ton buttressing stone continued and additional separation and displacement of dolos occurred in the lower seaward quadrant. Photos 187-189 show the structure after cumulative testing of Hydrograph A and B. Based on the overall test results, it appears that the stability of Plan 24 is questionable.

55. Plan 25 (Plate 27 and Photos 190-192) utilized the best merits of Plan 18 and Plan 24. A trench, approximately one dolos wide, was excavated starting above water at the end of the existing concrete cap and ending at -1 ft mllw. A rock buttress, consisting of 25-ton armor stone two layers deep and about 60 ft wide, was then placed around the outer perimeter of the seaward transition, starting at the end of the trench and proceeding below water to a depth of about -30 ft mllw. Special placement was used for the dolos toe units. After the dolosse were placed, voids in the trench were backfilled with material left over from the excavation. A total of 420 42-ton dolosse and 200 25-ton armor stone were placed. Plan 25 was subjected to the abbreviated hydrograph with marginal results. The rock buttress sloughed off to about a water depth of -5 ft mllw. Four dolosse were displaced at the seaward transition toe approximately where the trench ended and there was additional separation in this area. Photos 193-195 show the structure after testing. Although Plan 25 appeared questionable, it was felt worthwhile to continue testing. Plan 25 was rebuilt and subjected to Hydrograph A. A total of 412 42-ton dolosse and 154 25-ton armor stone were placed. The structure survived the storm up to the +10 ft swl where damage originated at the end of the trench. The damage progressed shoreward as the storm continued and a total of 14 dolosse were displaced. At this time, it was determined that the trench should extend into deeper water. Photos 196-198 show the structure after testing with Hydrograph A. It was felt that the dolosse movement was extensive enough to preclude acceptability of this plan.

56. Plan 26 (Plate 28 and Photos 199-201) was similar to Plan 25, except that the trench ended at a depth of -5 ft mllw and the rock barricade started at -2 ft mllw. A total of 410 42-ton dolosse and 152 25-ton armor stone were placed. Plan 26 was subjected to Hydrograph A. There was some separation of units along the shoreward transition and three units were

displaced along the toe, but this movement was considered acceptable. The rock buttress sloughed off to a depth of approximately -5 ft mllw; however, dolosse in the seaward transition area remained stable throughout Hydrograph A. Photos 202-204 show the structure after testing with Hydrograph A. Testing was then continued using Hydrograph B without rebuilding the structure. The structure remained stable throughout the second hydrograph. Photos 205-207 show the structure after cumulative testing of Hydrograph A and B. Plan 26 was rebuilt and again subjected to Hydrograph A. A total of 409 42-ton dolosse and 152 25-ton armor stone were placed. The structure survived the storm up to the +10 mllw still water level. Damage initiated at the end of the trench for this water level and progressed shoreward as the storm continued; a total of 10 dolosse were displaced. Photos 208-210 show the structure after testing. Although the damaged area eventually appeared to stabilize, it was felt worthwhile to repeat testing of Plan 26 with Hydrograph A again. A total of 415 42-ton dolosse and 154 25-ton armor stone were placed during rebuilding. Plan 26 performed satisfactorily for this repeat test. Photos 211-213 show the results. Based on these test results, -5 ft mllw is the minimum allowable depth at which the trench should end and Plan 26 appears to be a viable option for stability from wave direction 1.

57. Plan 27 (Plate 29 and Photos 214-216) was constructed with a berm of 25-ton armor stone placed offshore of the structure in an attempt to trip the wave and dissipate energy before it reached the seaward transition area. The berm was built after the dolosse were placed and had an average elevation of approximately -14 ft, which stayed about constant shoreward to where it transitioned into the existing breakwater material or dolosse. The berm transitioned from the -14 ft elevation to the sea floor over a distance of about 30 ft. Plate 29 shows a plan view of the stone placement. The rehabilitation dolosse were placed in the same geometry as for Plan 26, but no trenching or buttressing was used. A total of 410 42-ton rehabilitation dolosse and 354 25-ton stone were used. Plan 27 was subjected to the abbreviated hydrograph. The dolosse in the seaward transition area sustained extensive damage. Photos 217-219 show the structure after testing. The stone berm constructed in Plan 27 was not nearly large enough to dissipate the incoming wave energy, and it was surmised that it would take at least two to three times more volume of stone selectively placed in order for wave attenuation to occur. Based on

discussions with the US Army Engineer District, Los Angeles, it was decided to discontinue testing of this plan.

Stability tests of Plans 18 and 26
for a 67.5-deg angle of wave attack

58. Plan 18 (Plate 30 and Photos 220-222) was constructed the same as for the 90-deg angle of wave attack except for a modification to the shoreward transition. Two rows of rehabilitation dolosse encompassed the existing units at the shoreward end. A total of 434 42-ton rehabilitation dolosse were placed. Subjection to Hydrograph A displaced three dolosse from the shoreward transition toe. The seaward transition suffered extensive damage during testing with 13 units being displaced. Photos 223-225 show the structure after testing with Hydrograph A. Plan 18 was rebuilt using 447 42-ton rehabilitation dolosse and subjected to Hydrograph B. The seaward transition again sustained extensive damage and the shoreward transition had moderate damage. Thus, Plan 18 proved to be unacceptable for the 67.5-deg angle of wave attack. Photos 226-228 show the structure after testing with Hydrograph B.

59. Plan 26 (Plate 31 and Photos 229-231) was constructed the same as for the 90-deg angle of wave attack. A total of 410 42-ton dolosse and 135 25-ton armor stone were placed. Plan 26 was subjected to the abbreviated hydrograph with marginal results. Three dolosse were displaced from the lower shoreward transition toe, and seven or eight units separated from the dolos mat in this area. Two units were displaced from the seaward transition but they did not affect the overall stability of this region. There was considerably less sloughing off of the buttressing stone than from the other wave direction as waves tended to push the stone against the dolosse rather than wash it out the dogleg. Photos 232-234 show the structure after testing. The test section was rebuilt and subjected to the abbreviated hydrograph again, this time with satisfactory results. Photos 235-237 show Plan 26 after the repeat test. Plan 26 was rebuilt and subjected to Hydrograph A. A total of 417 42-ton dolosse and 135 25-ton armor stone were placed. There were five dolosse displaced from the shoreward transition toe and some separation of units occurred in this area; however, the region appeared to stabilize during testing and the amount of movement was considered acceptable. One unit was washed up on the cap near the center of the rehabilitation area. Photos 238-240 show the structure after testing. Plan 26 then was rebuilt with the same modification to the shoreward transition as for Plan 18.

Photos 241-243 and Plate 31 show the modified plan before testing. A total of 434 42-ton dolosse and 135 25-ton stone were placed. The modified plan was subjected to Hydrograph B with satisfactory results. Three dolosse were displaced from the shoreward transition and one from the seaward transition. Photos 244-246 show the test section after testing with Hydrograph B.

PART IV: CONCLUSIONS

60. Based on test results and observations presented herein, it is concluded that:

- a. Plans 1-6, 9-16, 19-23, 25, and 27 are not acceptable.
- b. Plans 7 and 8 had minor damage of the rehabilitation dolos; however, the existing dolosse extending seaward of sta 37+00 were damaged for the selected test conditions.
- c. Plan 17 performed satisfactorily when subjected to the abbreviated hydrograph at a 90-deg angle of wave attack; however, it was found that the number of dolosse in the seaward transition could be reduced, thus creating Plan 18.
- d. Plan 18 was acceptable for the 90-deg but not the 67.5-deg angle of wave attack.
- e. Plan 24 was considered marginal for the 90-deg angle of wave attack. The rock buttress sloughed off during testing and stone was washed down the dogleg creating a risk to the existing tetrapods and leaving the rehabilitation dolosse at the seaward transition toe without protection.
- f. Plan 26 was acceptable for both the 90-deg and 67.5-deg angles of wave attack. Modifying the shoreward transition by encompassing existing units with two rows of rehabilitation dolosse seemed to improve the stability of this region.
- g. The end of the trench was referenced to mllw for Plans 18 and 26 to give an indication of constructability. Since the profile of the existing material varies and is flat in some places, it is suggested that for construction purposes the end of the trench be referenced to a horizontal distance measured from the outside edge of the cap. The minimum horizontal distances recommended from the model test results are 100 and 35 ft for Plans 18 and 26, respectively.

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Table 1
Abbreviated Hydrograph


Step	swl ft mllw	Step Length min	Test Wave	
			Period sec	Height ft
1	-1	15	15	24.8
2	-1		18	22.5
3	-1		21	25.4
4	+4		15	29.0
5	+4		18	23.7
6	+4		21	30.5
7	+7		15	29.8
8	+7		18	29.8
9	+7		21	32.4
10	+10		15	31.0
11	+10		18	32.1
12	+10		21	33.0

Table 2
Hydrograph A

Step	swl ft mllw	Step Length min	Test Wave	
			Period sec	Height ft
1	+4	20	15	29.0
2	+4	↓	18	23.7
3	+4		21	30.5
4	-1		15	24.8
5	-1		18	22.5
6	-1		21	25.4
7	+4		15	29.0
8	+4		18	23.7
9	+4		21	30.5
10	+7	40	15	29.8
11	+7	40	18	29.8
12	+7	40	21	32.4
13	+10	60	15	31.0
14	+10	60	18	32.1
15	+10	60	21	33.0
16	+7	40	15	29.8
17	+7	40	18	29.8
18	+7	40	21	32.4
19	+4	20	15	29.0
20	+4	↓	18	23.7
21	+4		21	30.5
22	-1		15	24.8
23	-1		18	22.5
24	-1		21	25.4

Table 3
Hydrograph B

Step	swl ft mllw	Step Length min	Test Wave	
			Period sec	Height ft
1	+7	40	15	29.8
2	+7	40	18	29.8
3	+7	40	21	32.4
4	+10	60	15	31.0
5	+10	60	18	32.1
6	+10	60	21	33.0
7	+7	40	15	29.8
8	+7	40	18	29.8
9	+7	40	21	32.4
10	+4	20	15	29.0
11	+4	↓	18	23.7
12	+4		21	30.5
13	-1		15	24.8
14	-1		18	22.5
15	-1		21	25.4
16	+4		15	29.0
17	+4		18	23.7
18	+4		21	30.5

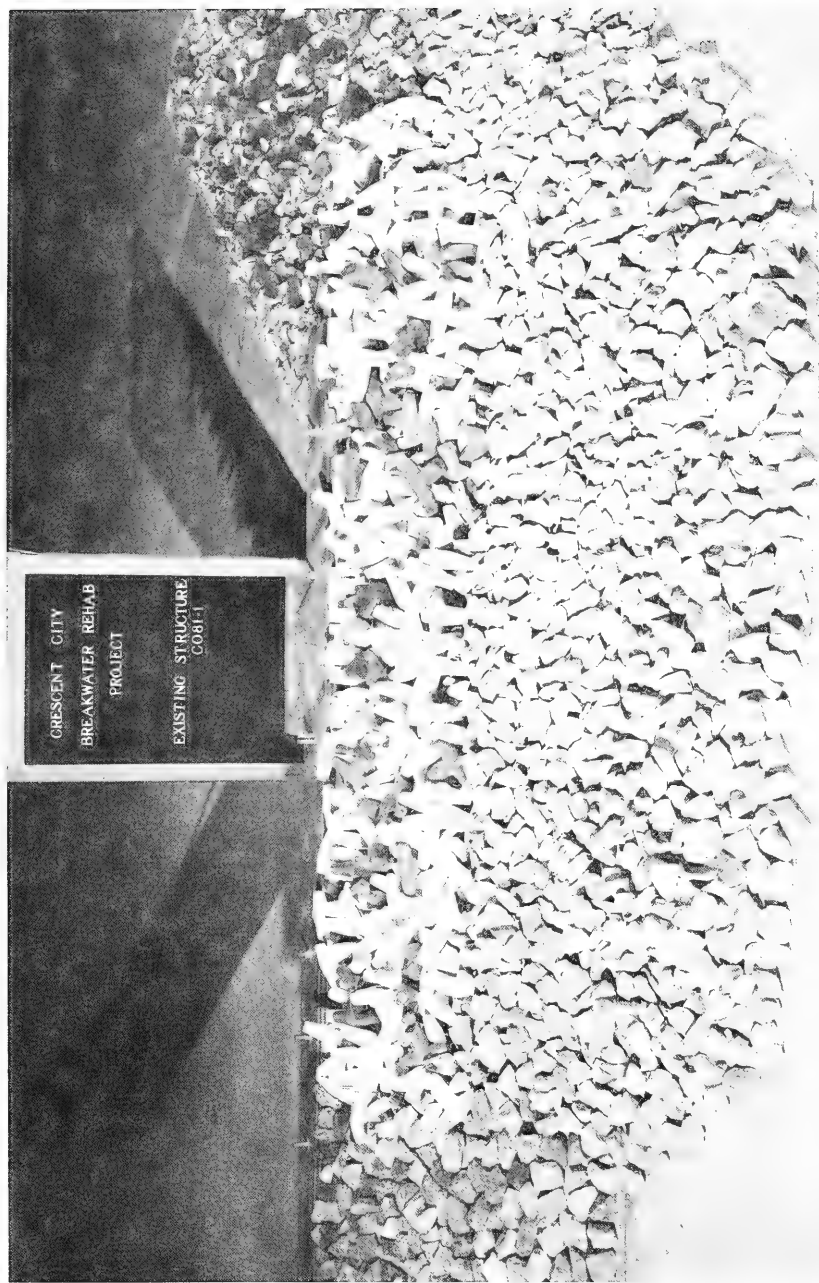


Photo 1. Sea-side view of existing structure



Photo 2. Seaward oblique view of existing structure

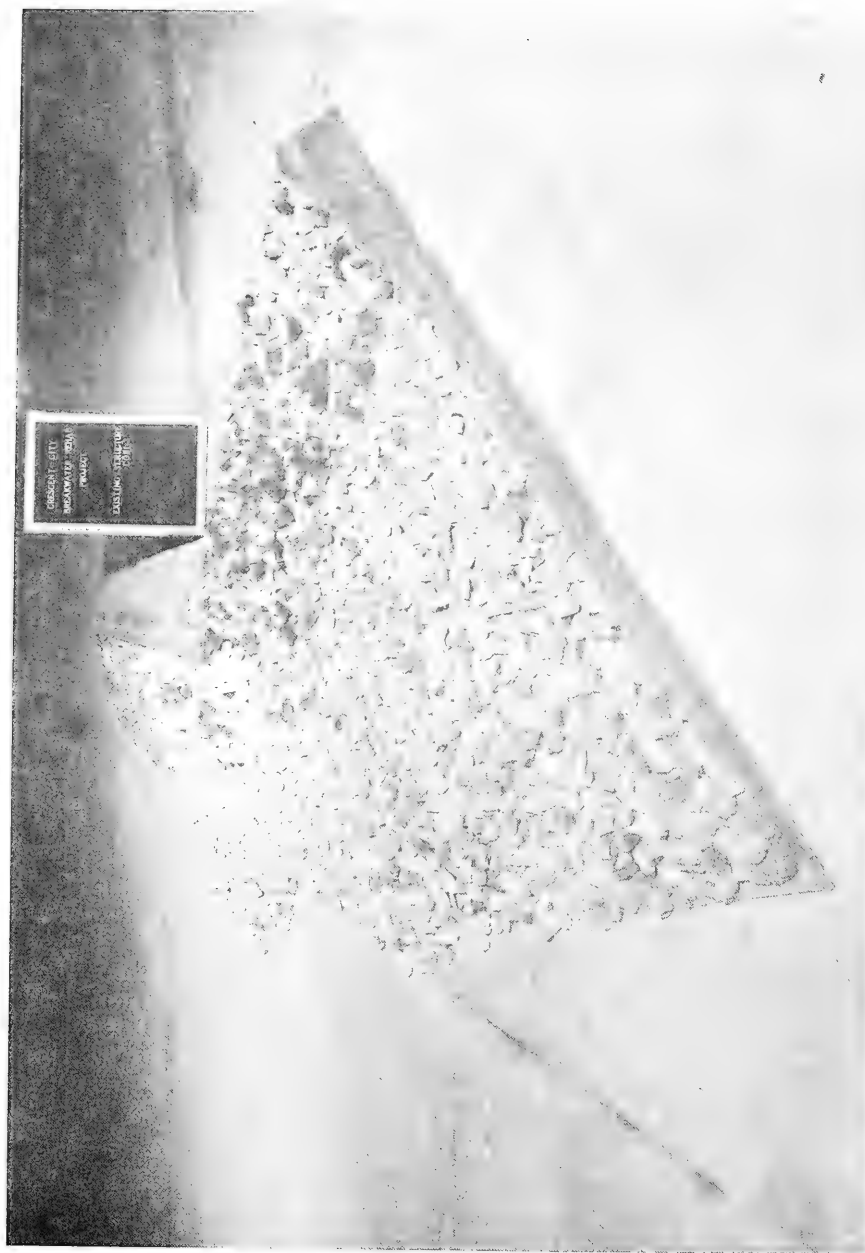


Photo 3. Seaward end view of existing structure



Photo 4. Harbor-side view of existing structure

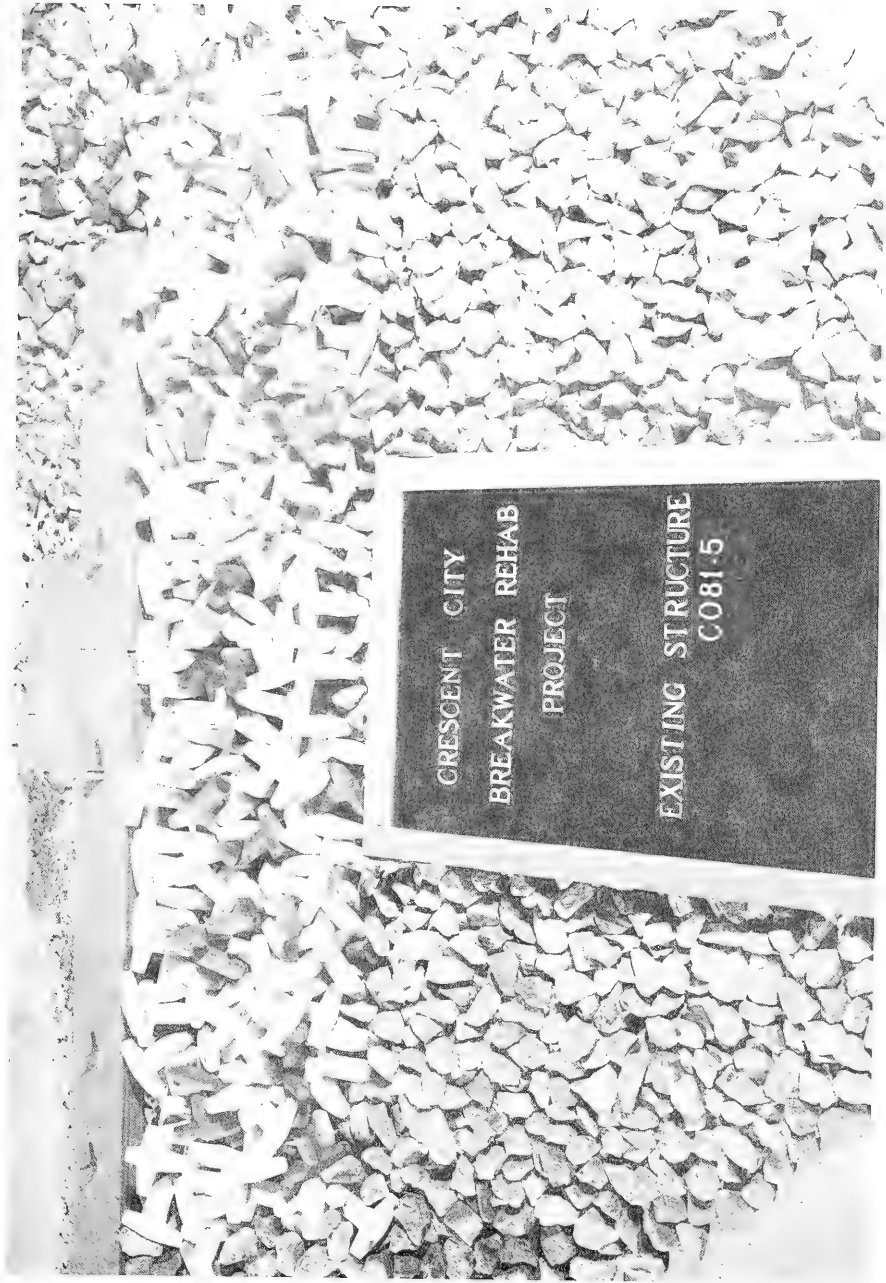


Photo 5. Shoreward end view of existing structure



Photo 6. Close-up of dolosse in existing structure



Photo 7. Sea-side view of Plan 1 before wave attack

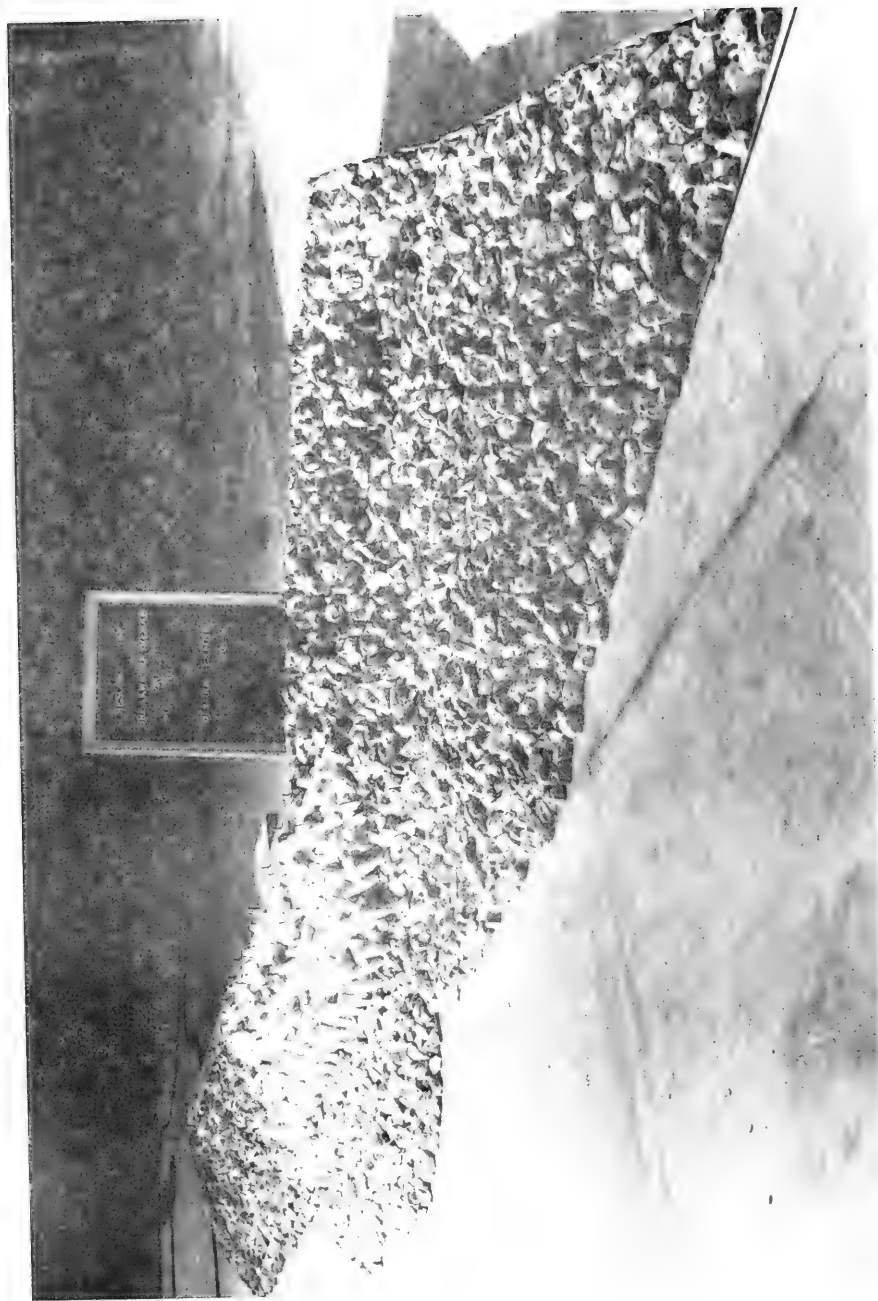


Photo 8. Seaward oblique view of Plan 1 before wave attack



Photo 9. Seaward end view of Plan 1 before wave attack

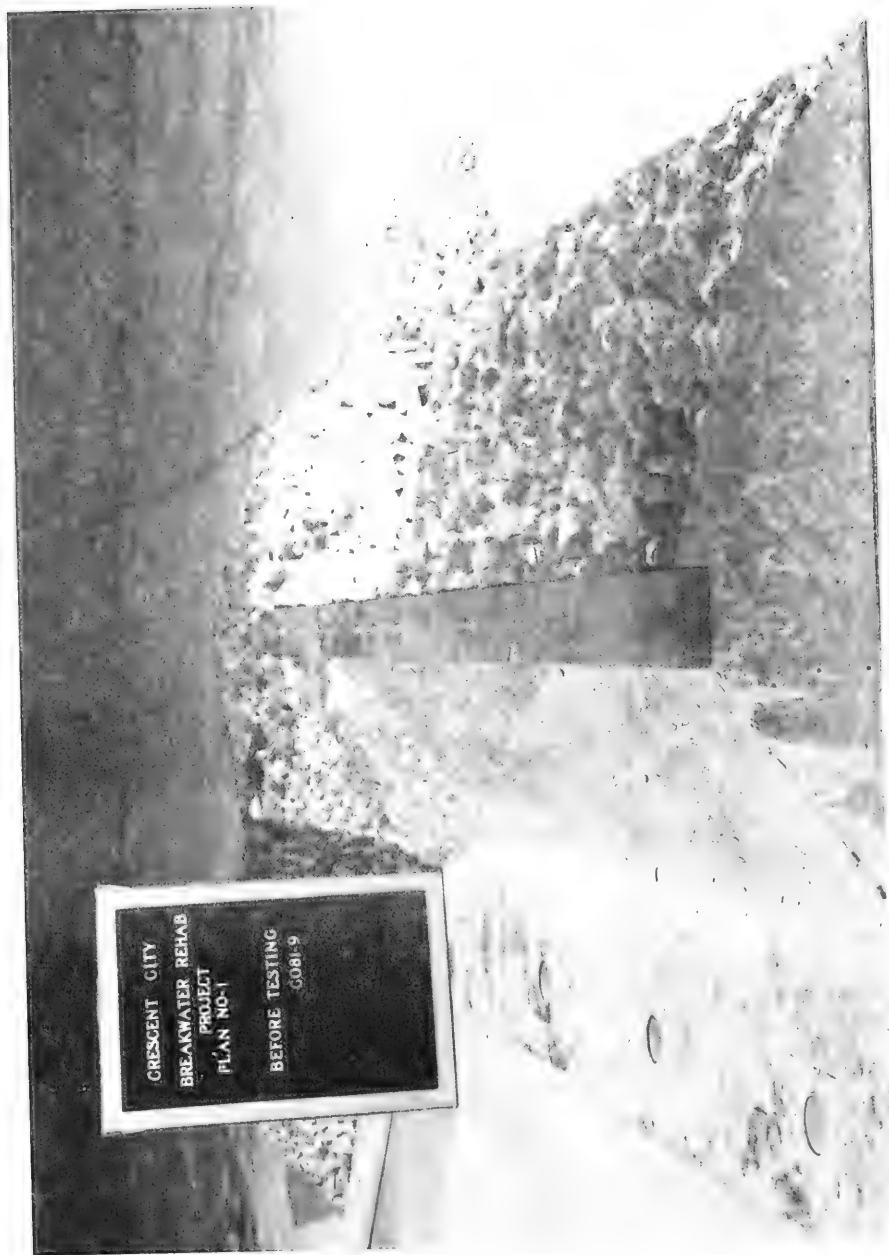


Photo 10. Shoreward end view of Plan 1 before wave attack

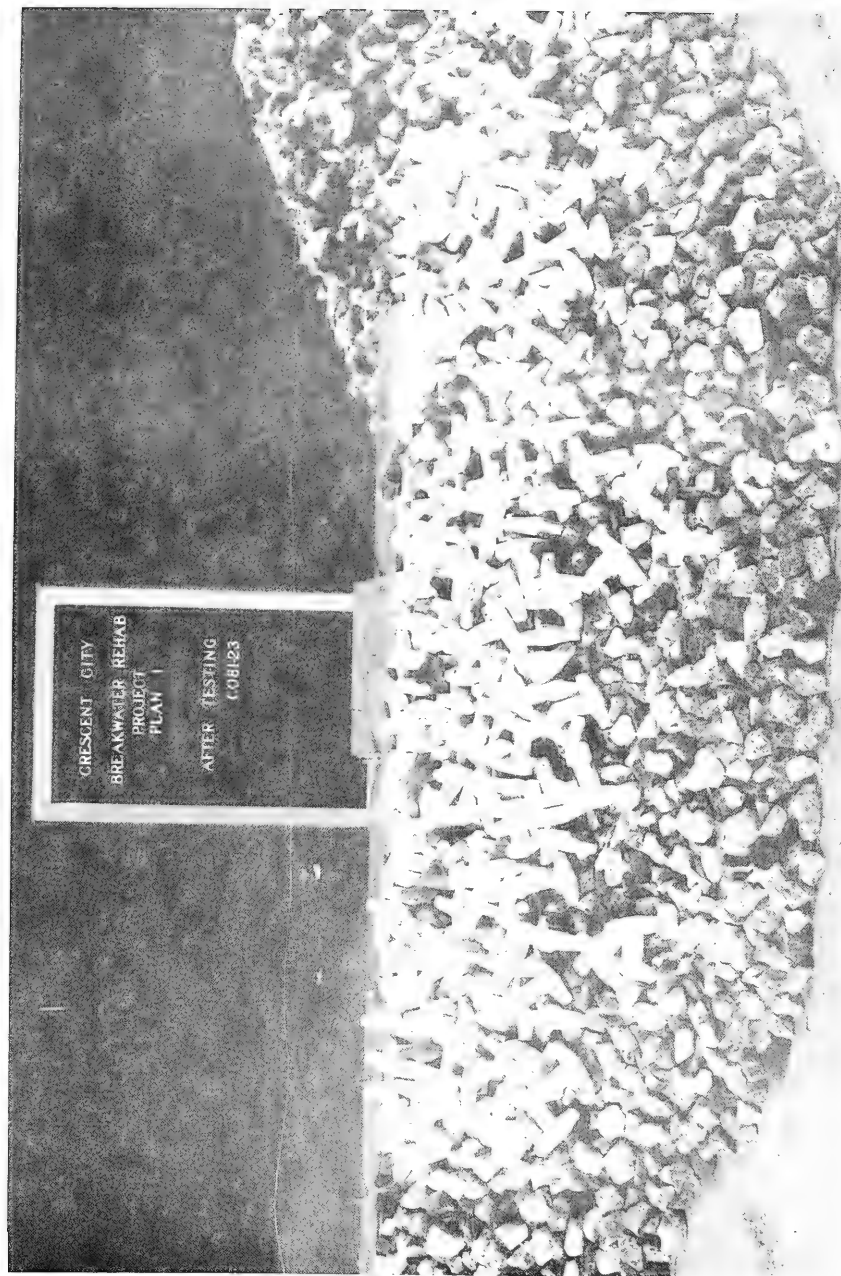


Photo 11. Sea-side view of Plan 1 after completion of abbreviated hydrograph



Photo 12. Seaward oblique view of Plan 1 after completion of abbreviated hydrograph



Photo 13. Seaward end view of Plan 1 after completion of abbreviated hydrograph

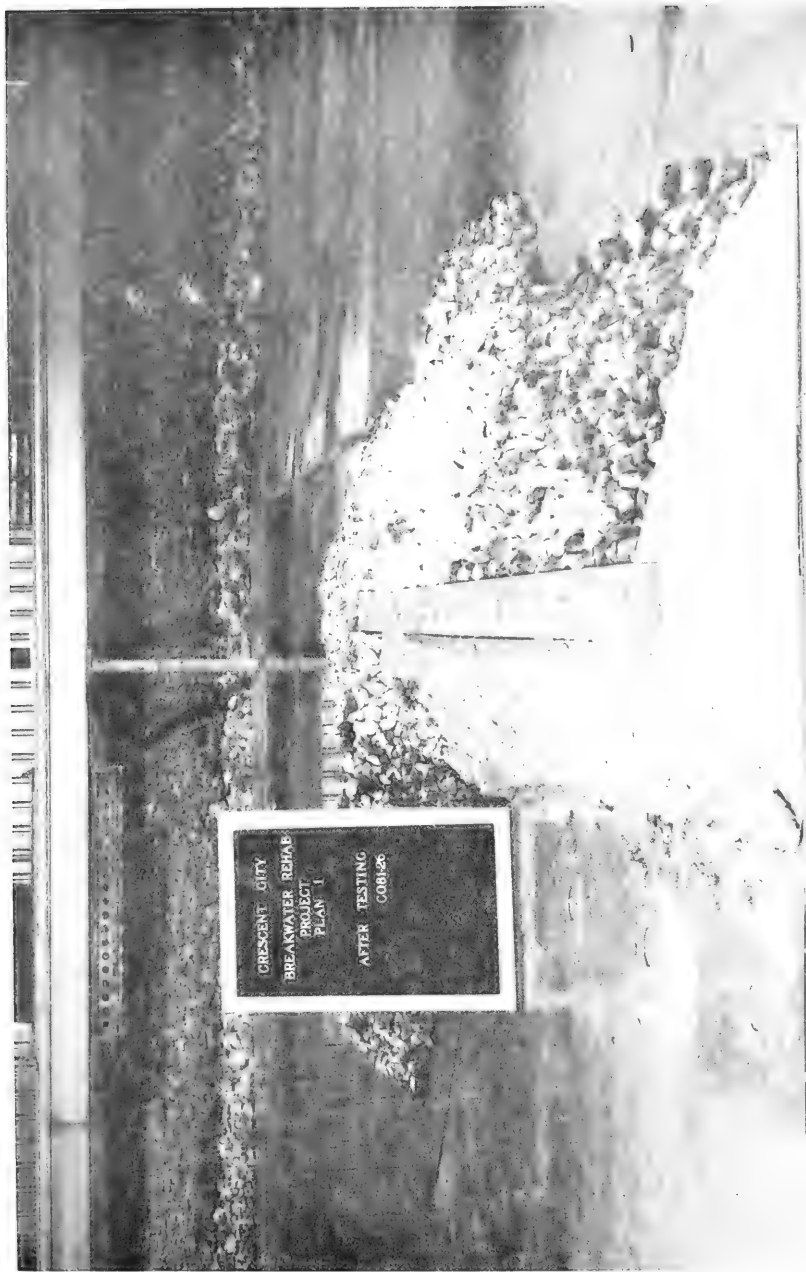


Photo 14. Shoreward end view of Plan 1 after completion of abbreviated hydrograph

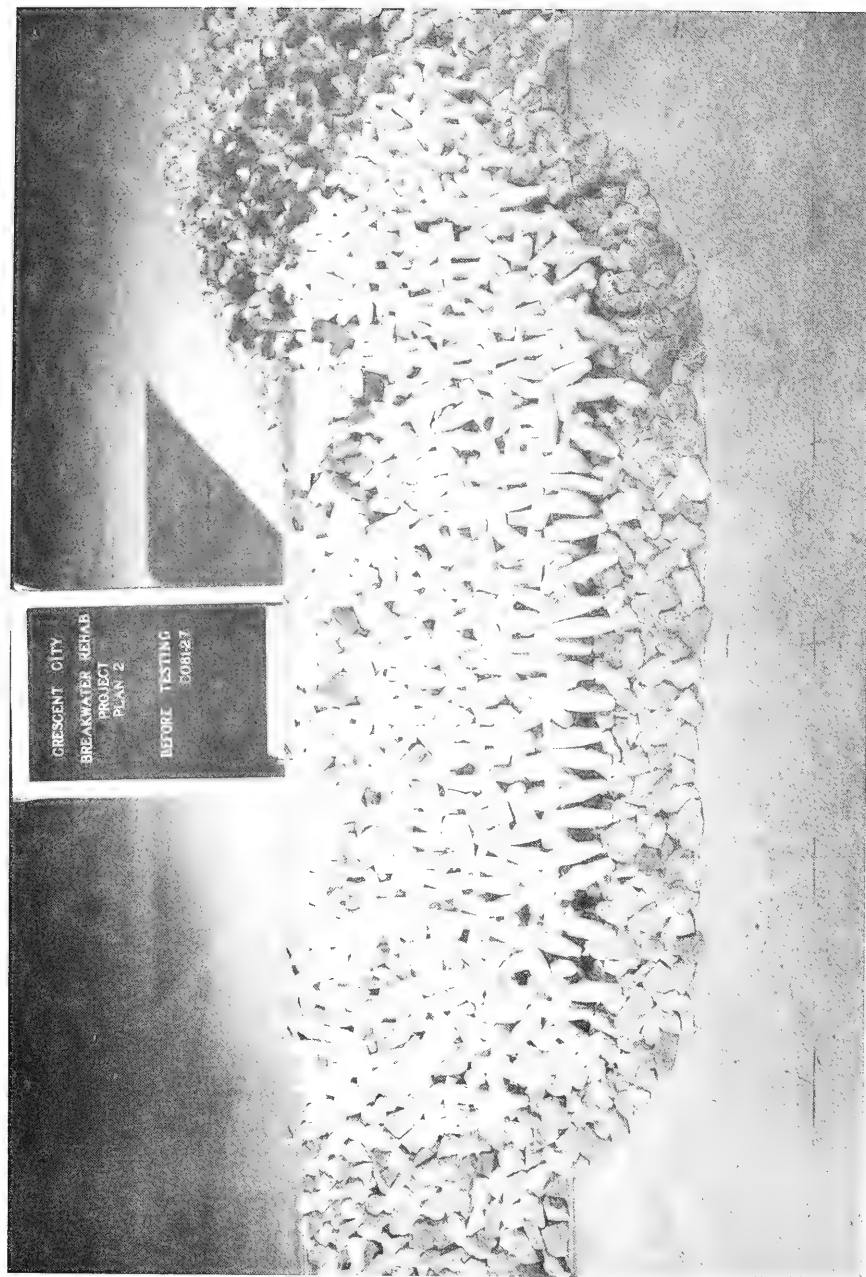


Photo 15. Sea-side view of Plan 2 before wave attack



CORREKT CITY
SEAWARD SIDE
PLAN 2
BEFORE TESTING
CH128

Photo 16. Seaward oblique view of Plan 2 before wave attack

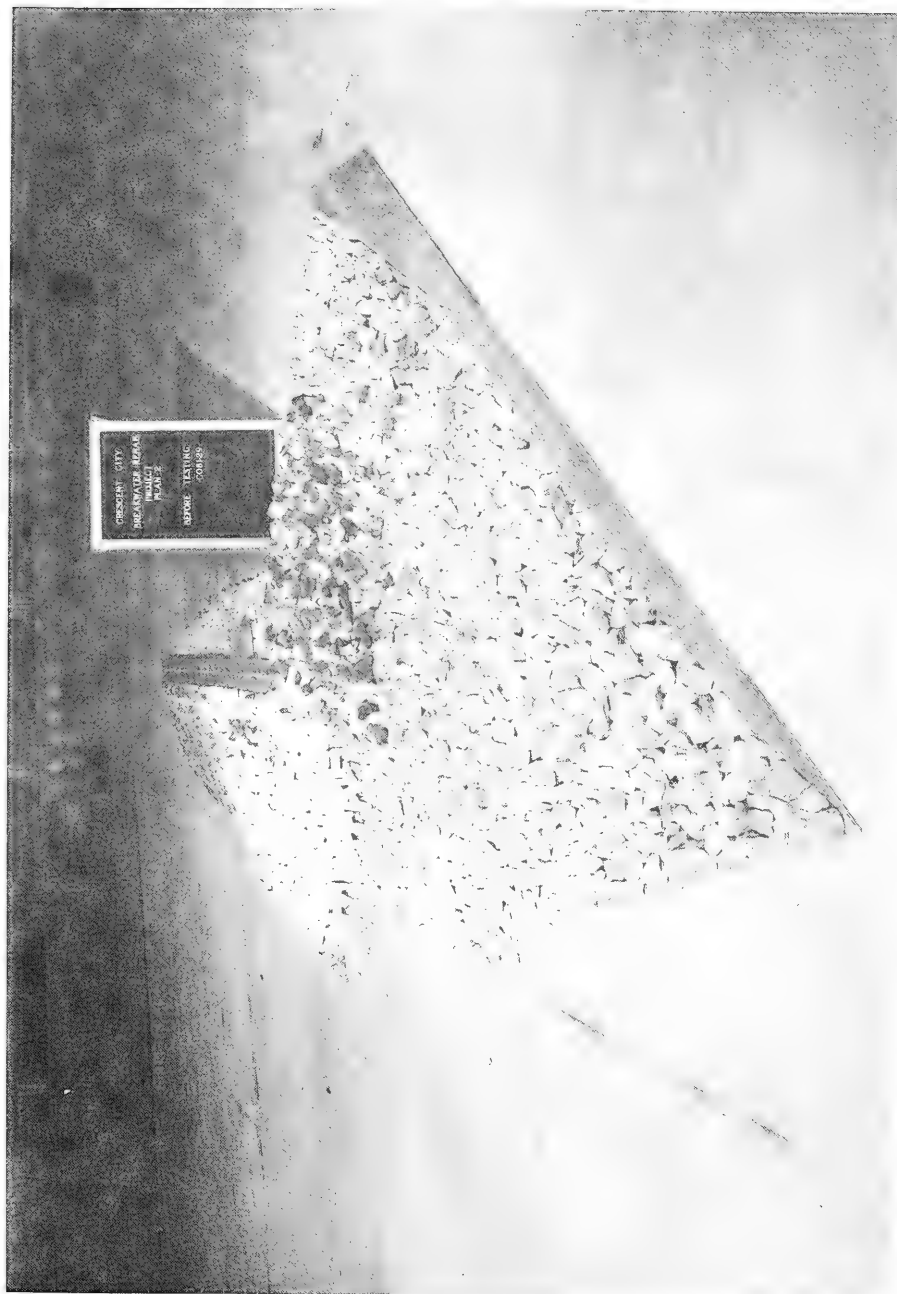


Photo 17. Seaward end view of Plan 2 before wave attack



Photo 18. Shoreward end view of Plan 2 before wave attack

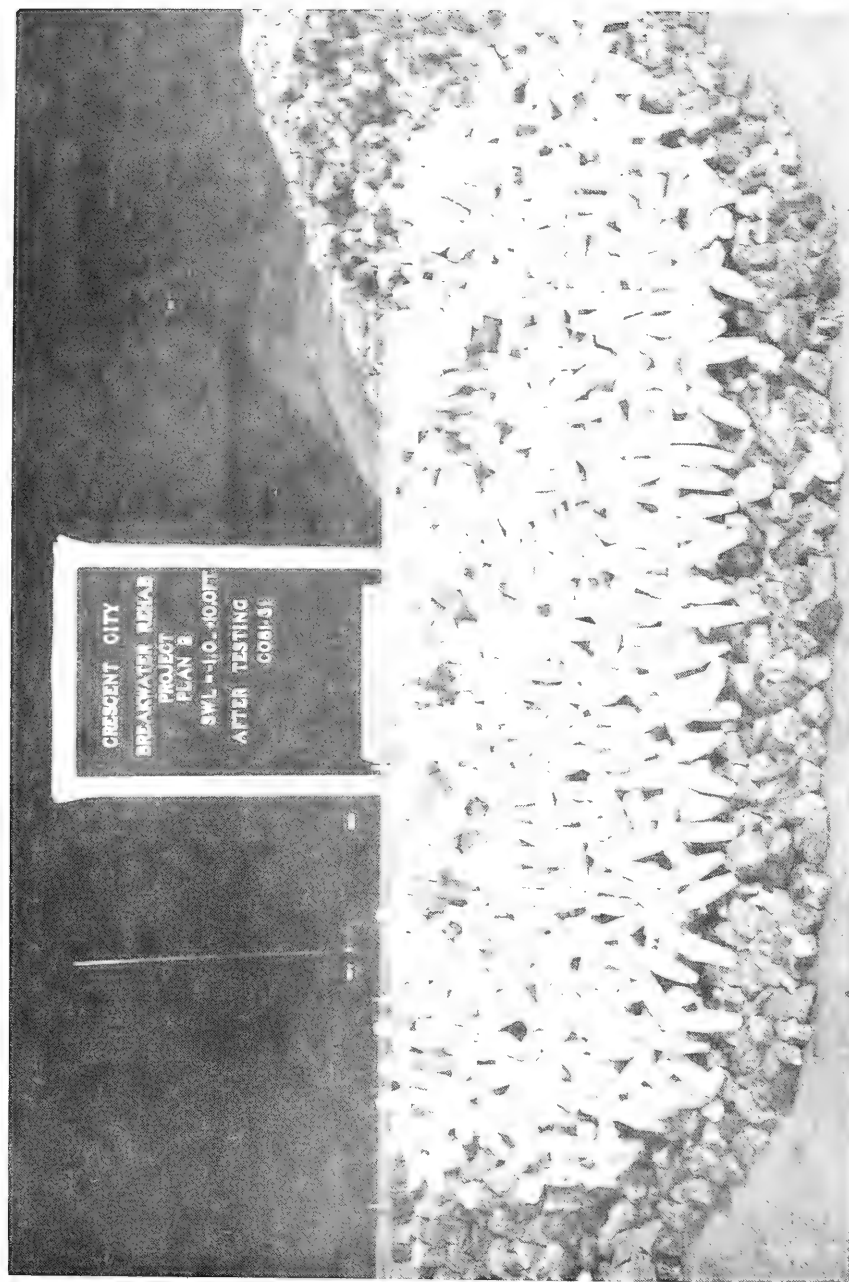


Photo 19. Sea-side view of Plan 2 after completion of abbreviated hydrograph

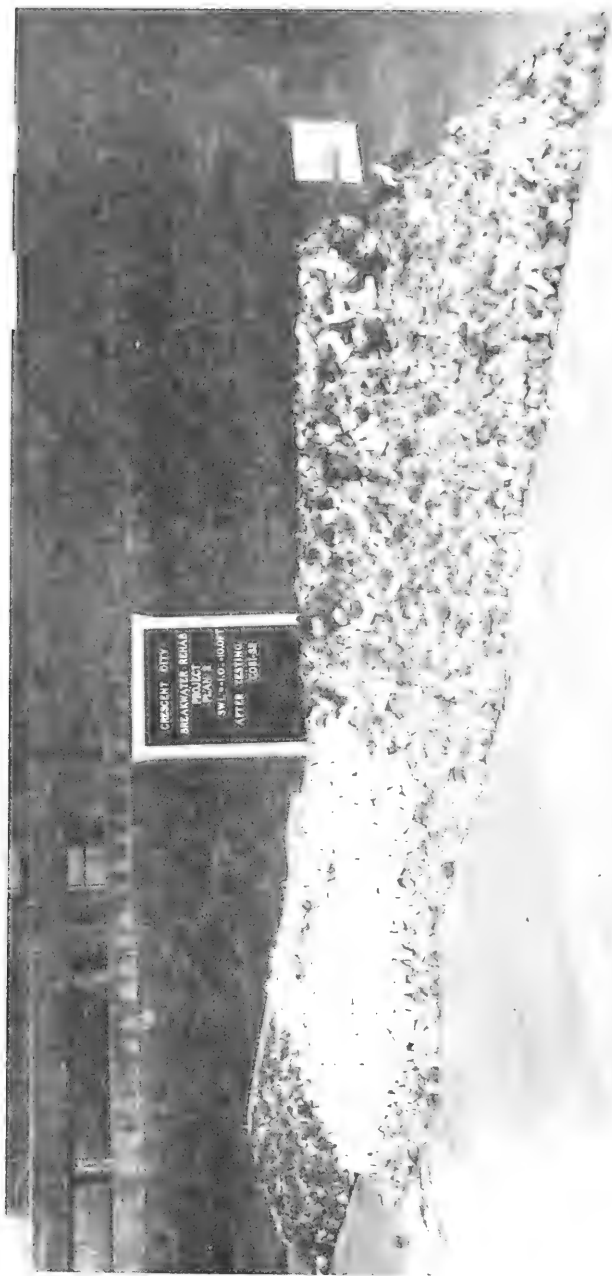


Photo 20. Seaward oblique view of Plan 2 after completion of abbreviated hydrograph

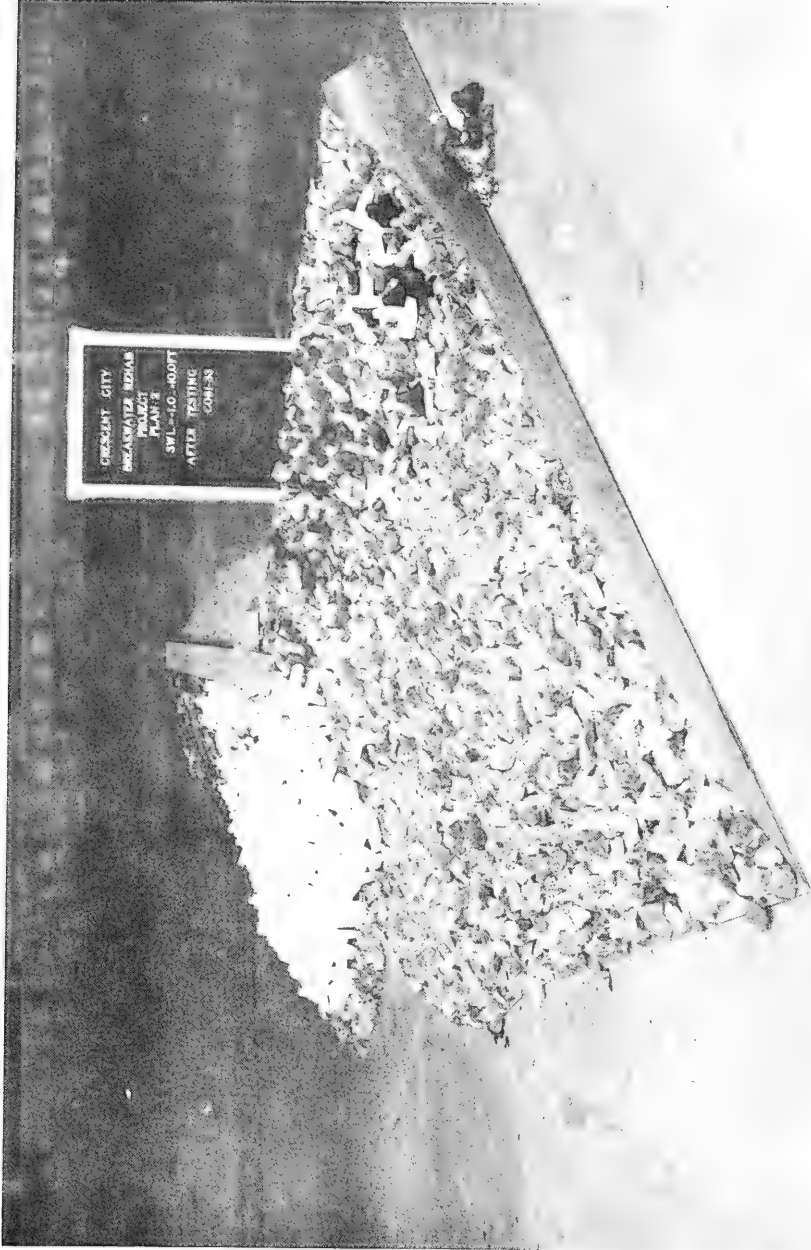


Photo 21. Seaward end view of Plan 2 after completion of abbreviated hydrograph

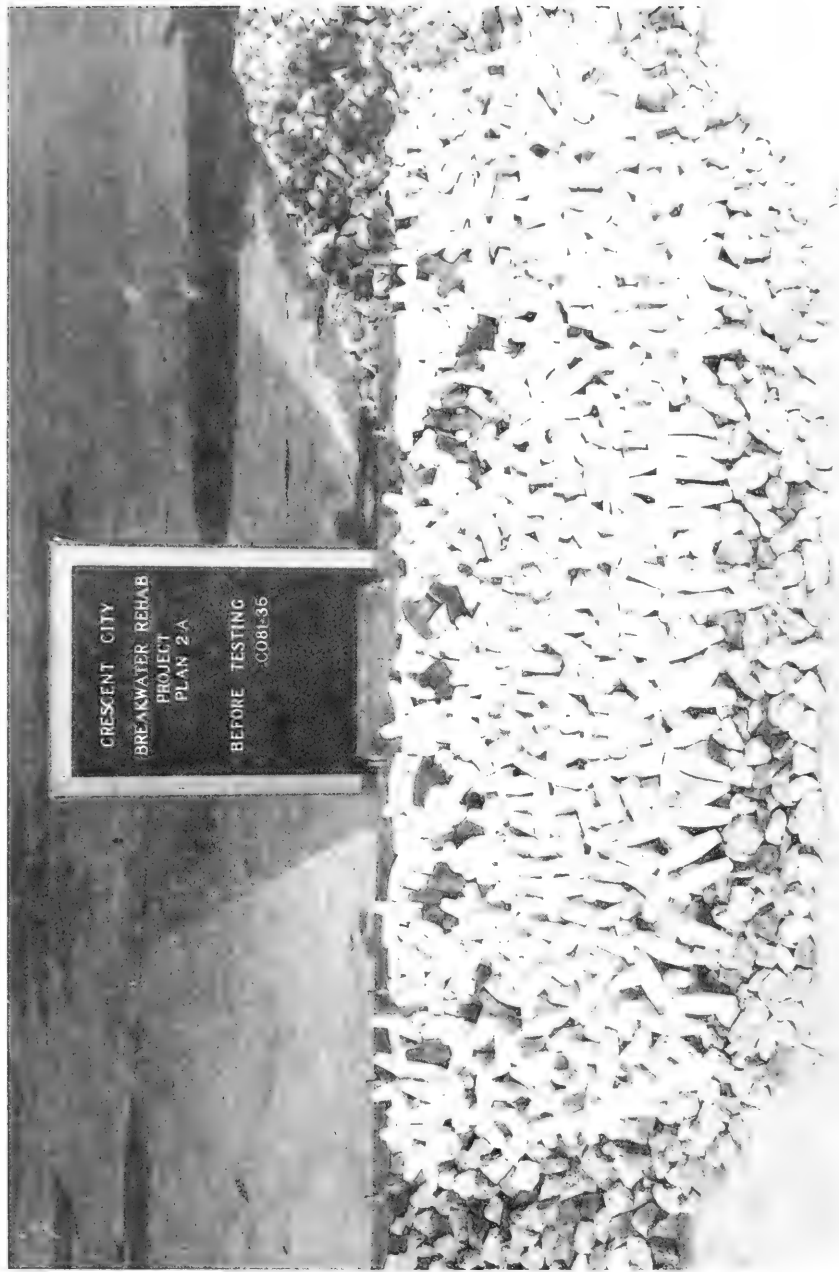


Photo 22. Sea-side view of Plan 2A before wave attack



Photo 23. Seaward oblique view of Plan 2A before wave attack



Photo 24. Sea-side view of Plan 2A after completion of abbreviated hydrograph



Photo 25. Seaward oblique view of Plan 2A after completion of abbreviated hydrograph



Photo 26. Seaward end view of Plan 2A after completion of abbreviated hydrograph

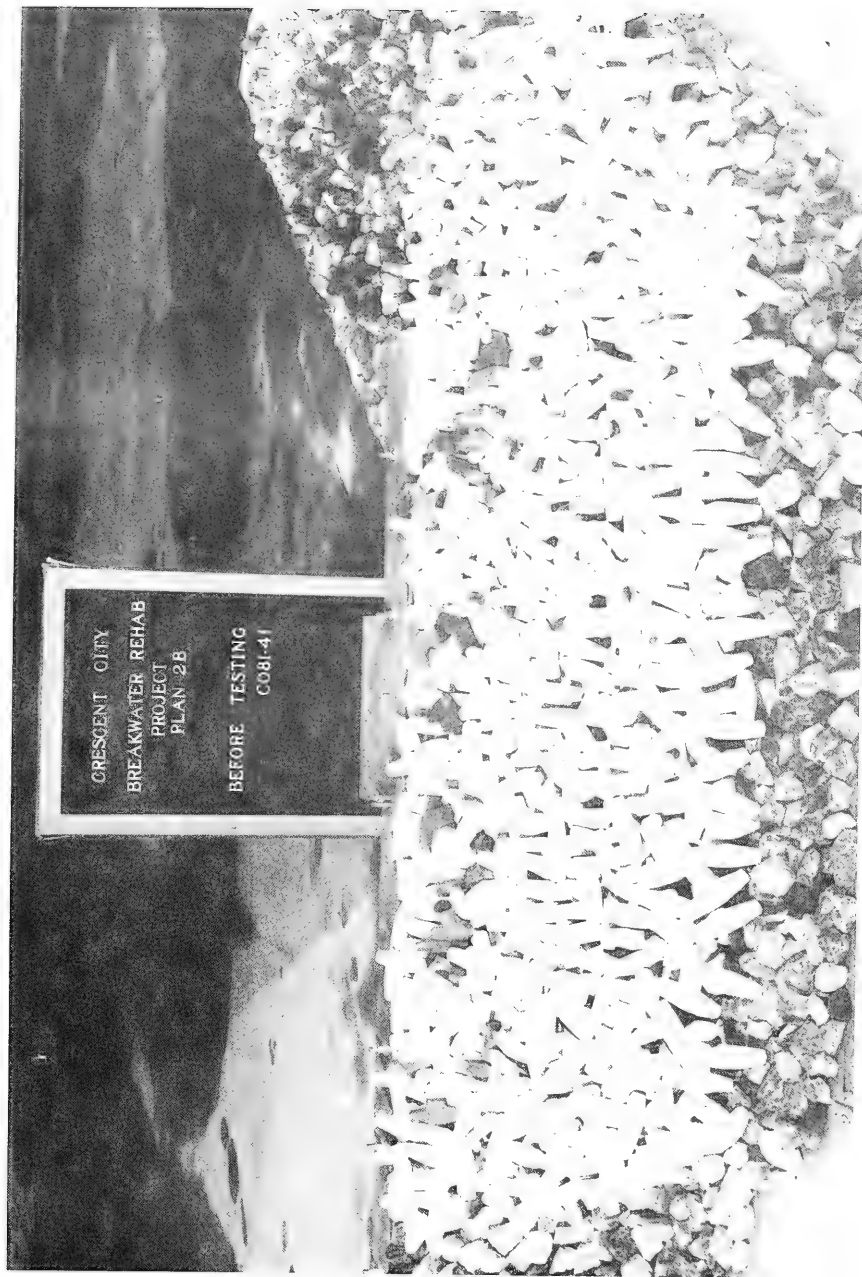


Photo 27. Sea-side view of Plan 2B before wave attack

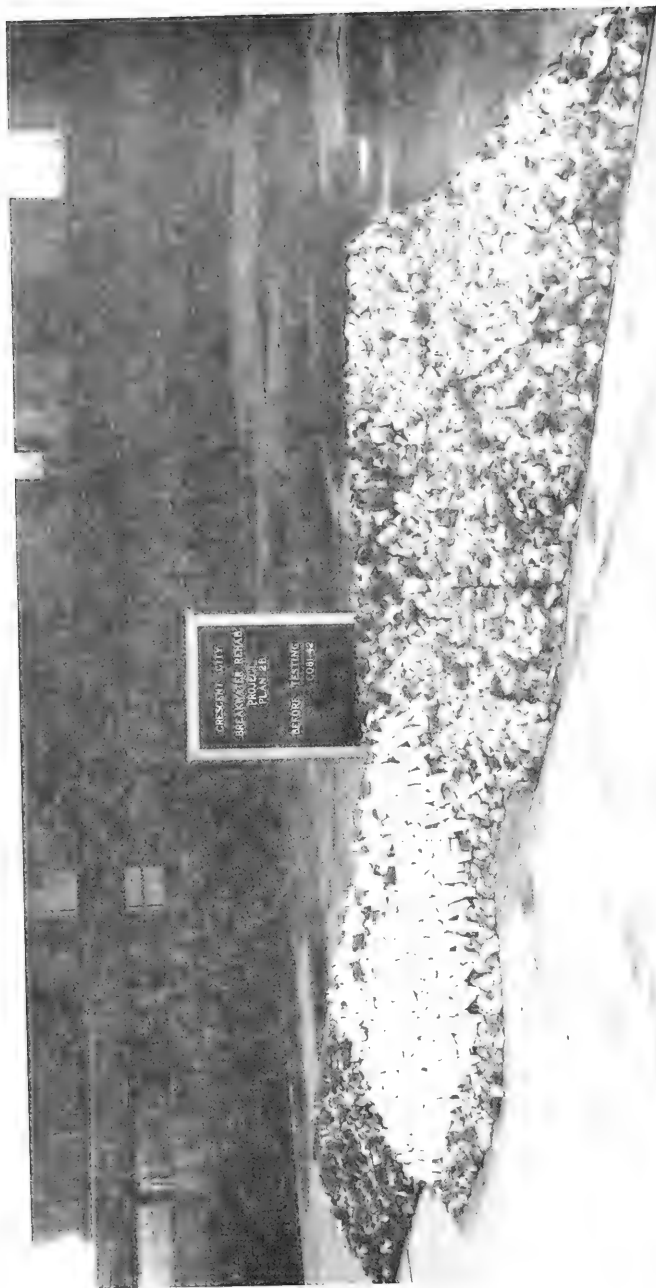


Photo 28. Seaward oblique view of Plan 2B before wave attack



Photo 29. Special toe placement used for seaward transition of Plan 2B

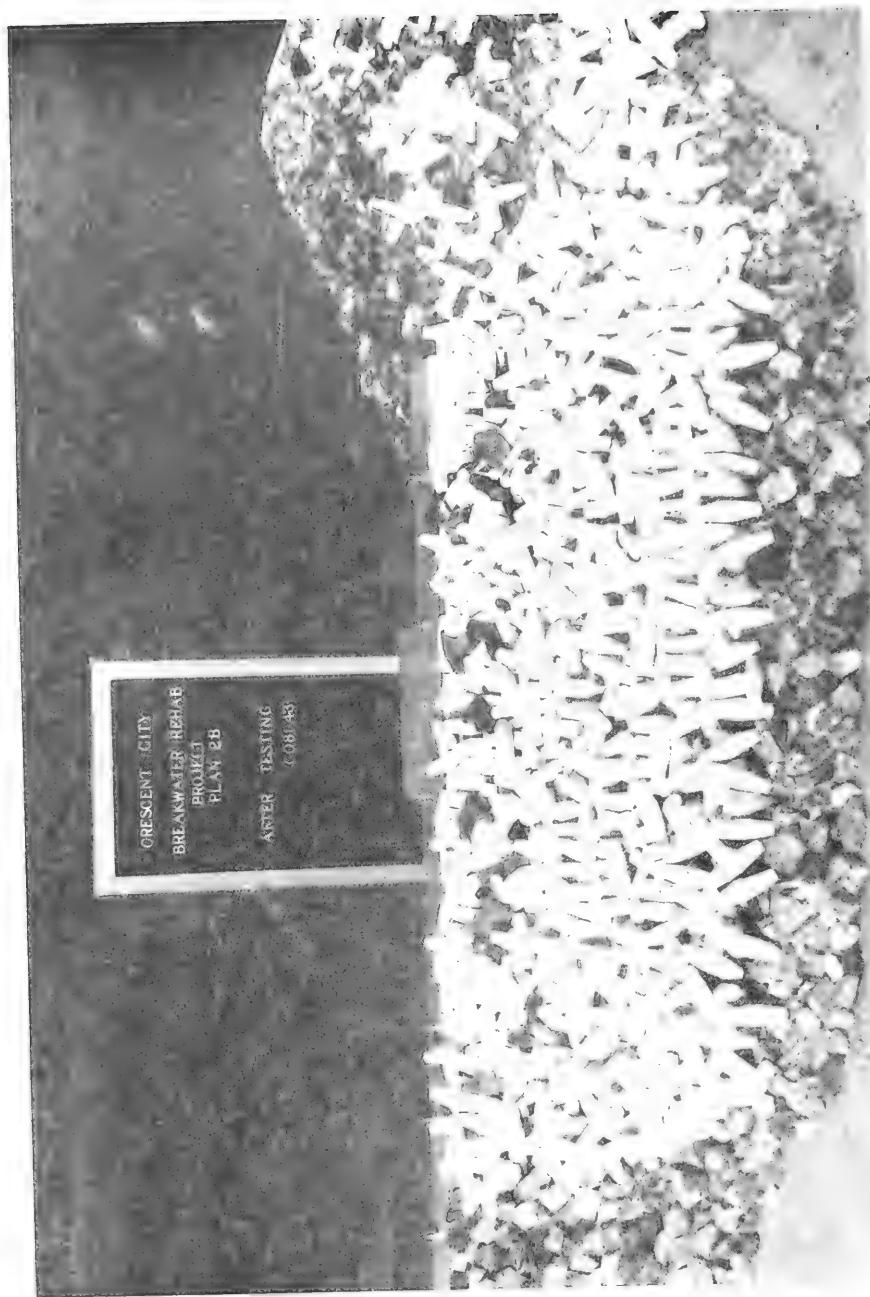


Photo 30. Sea-side view of Plan 2B after completion of abbreviated hydrograph



Photo 31. Seaward oblique view of Plan 2B after completion of abbreviated hydrograph



Photo 32. Seaward end view of Plan 2B after completion of abbreviated hydrograph

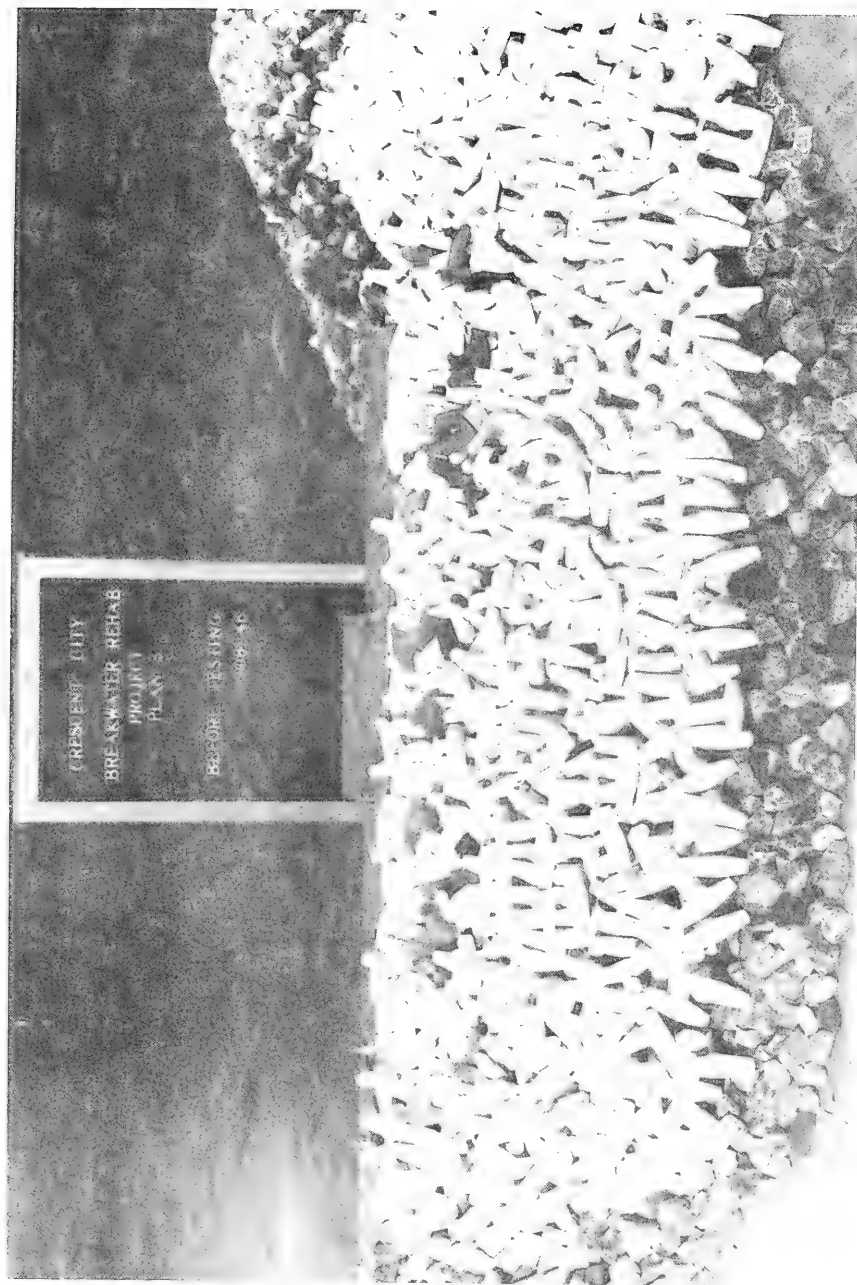


Photo 33. Sea-side view of Plan 3 before wave attack

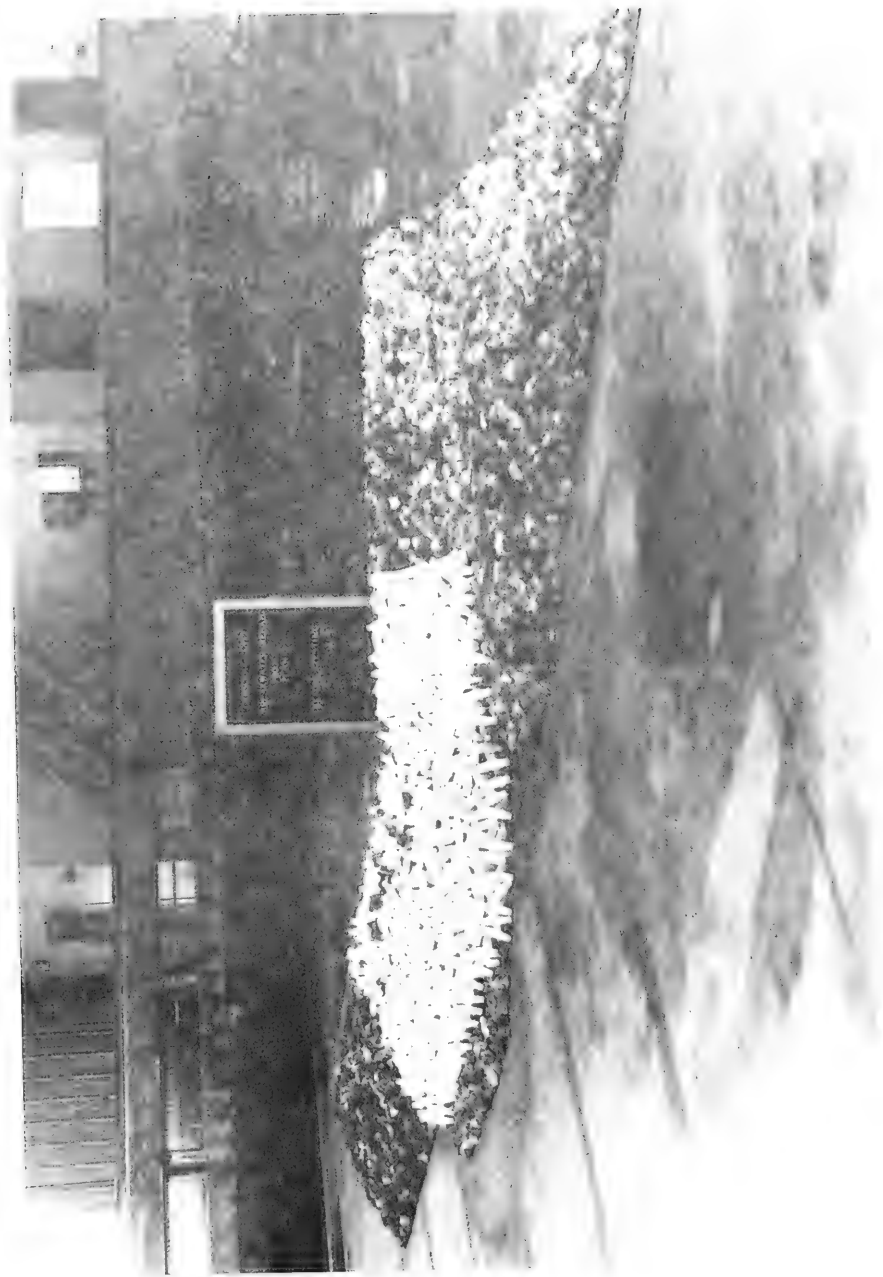


Photo 34. Seaward oblique view of Plan 3 before wave attack

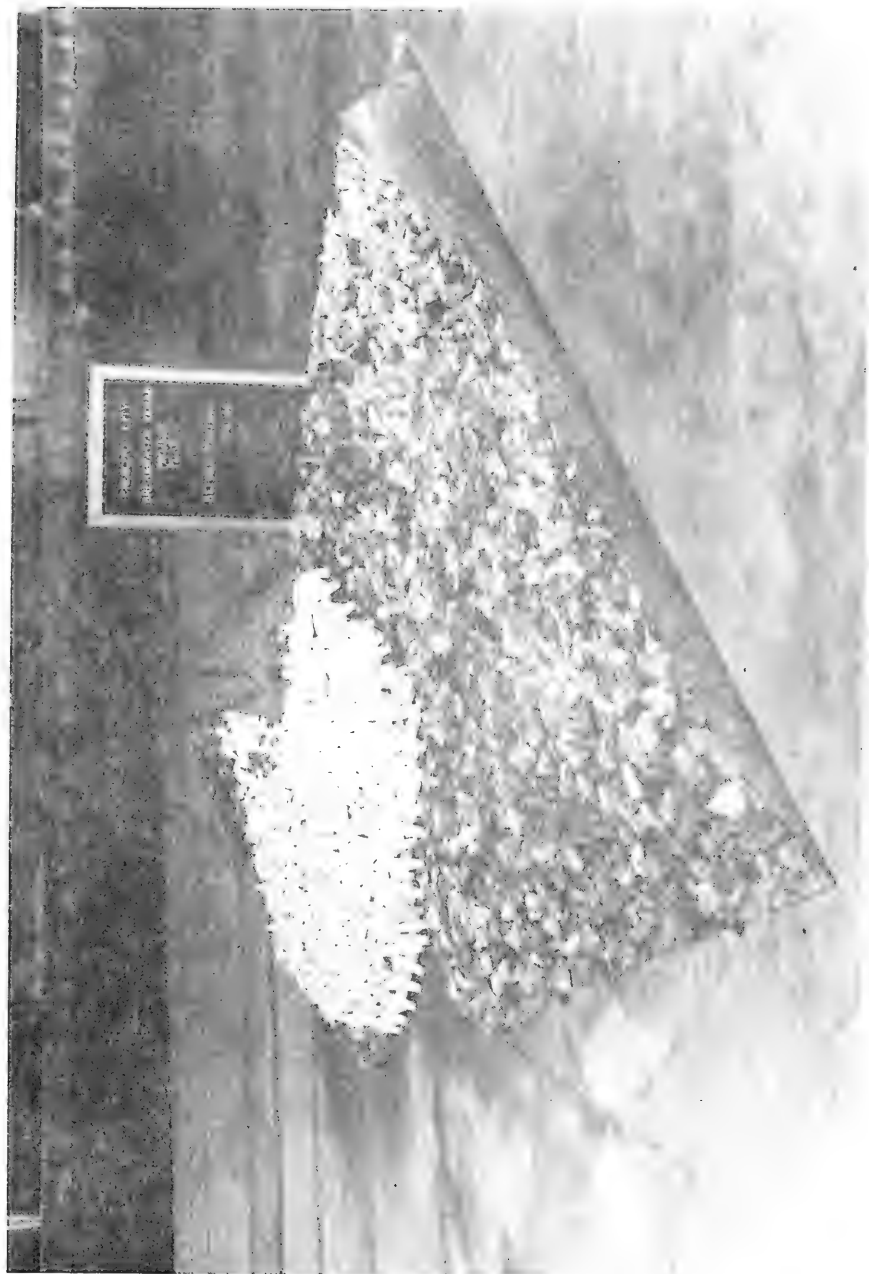


Photo 35. Seaward end view of Plan 3 before wave attack

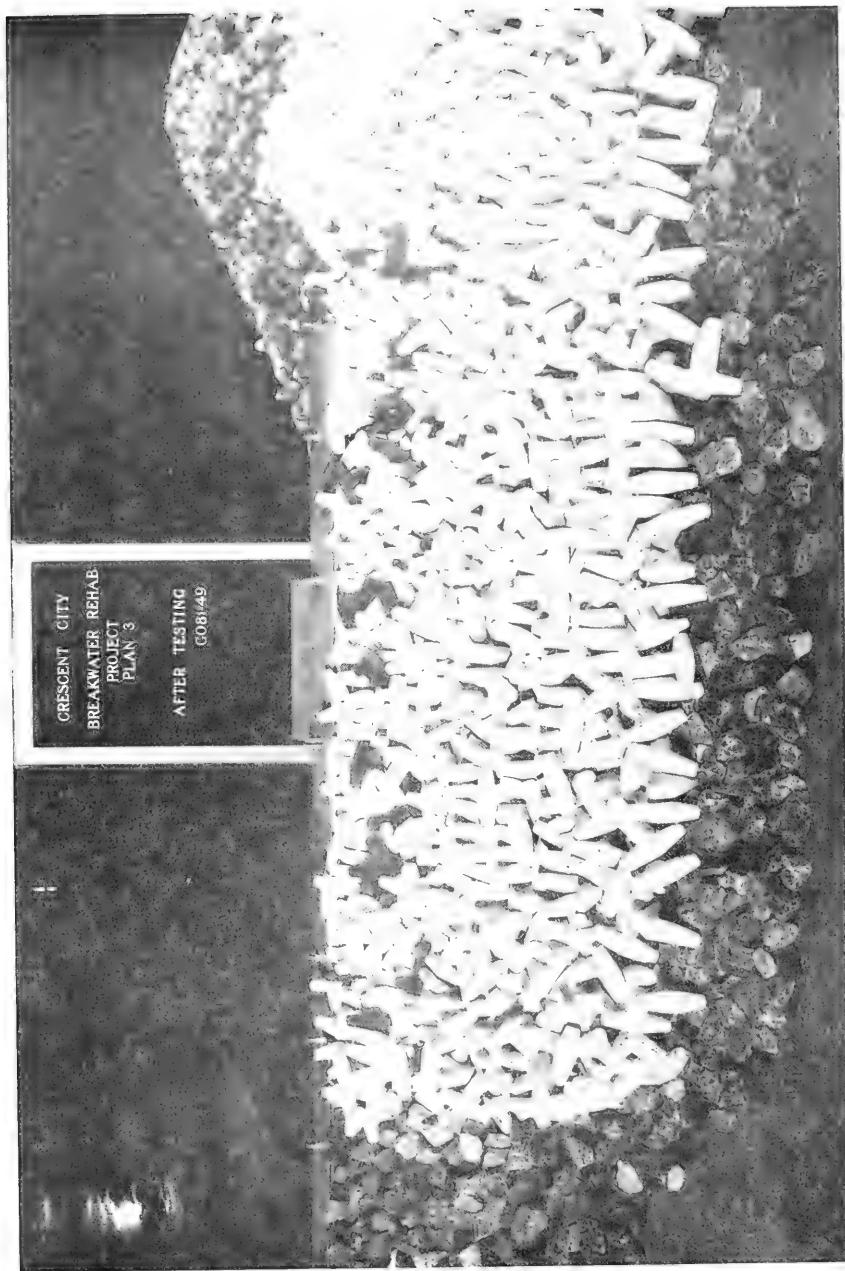


Photo 36. Sea-side view of Plan 3 after completion of abbreviated hydrograph



Photo 37. Seaward oblique view of Plan 3 after completion of abbreviated hydrograph

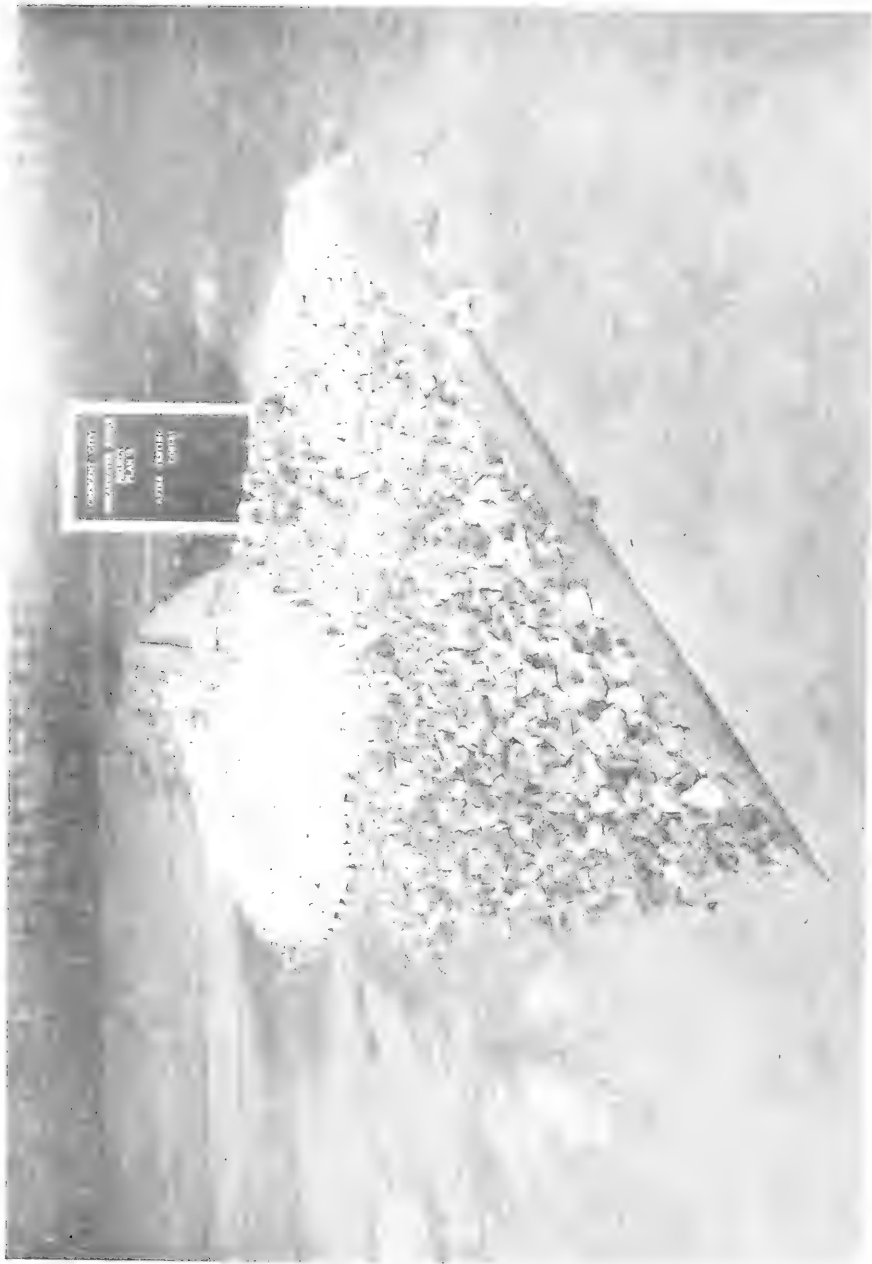


Photo 38. Seaward end view of Plan 3 after completion of abbreviated hydrograph

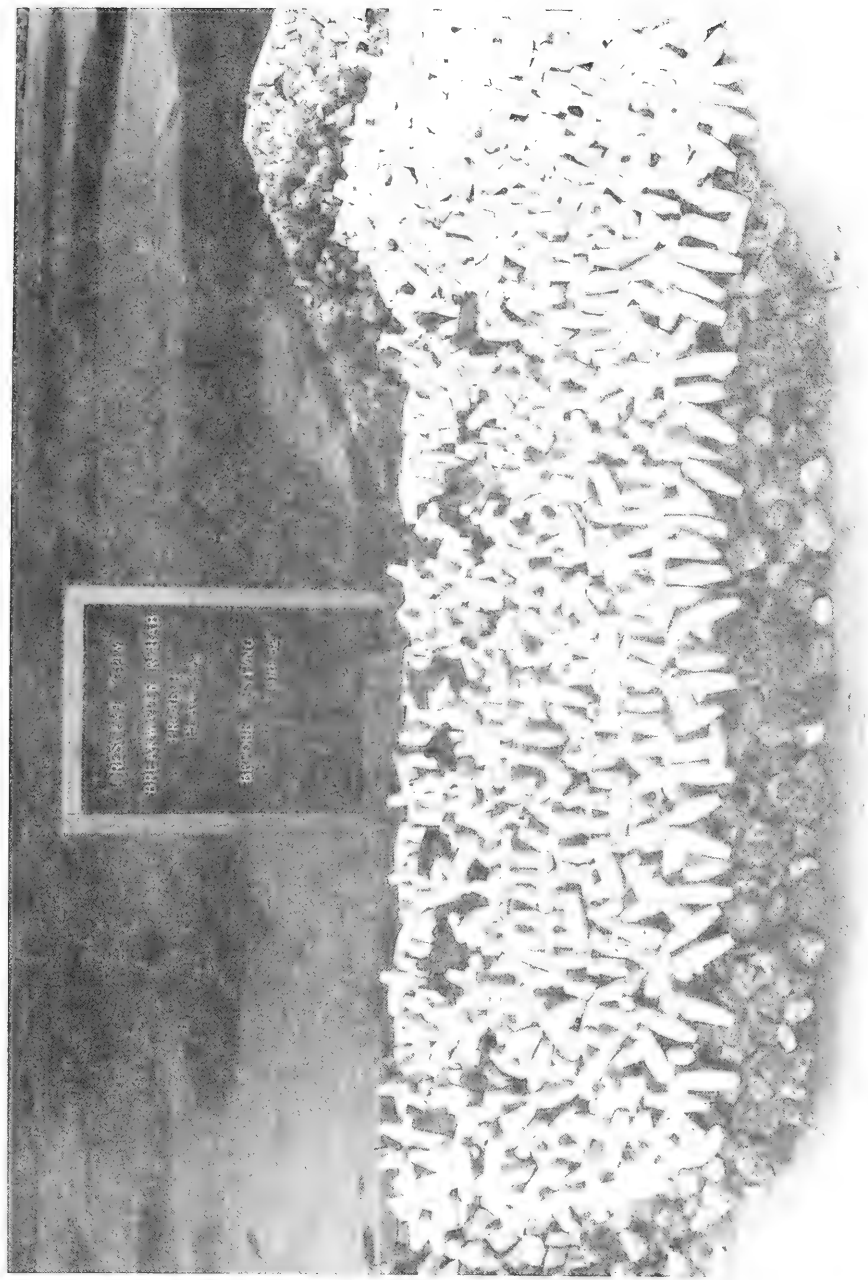


Photo 39. Sea-side view of Plan 3A before wave attack

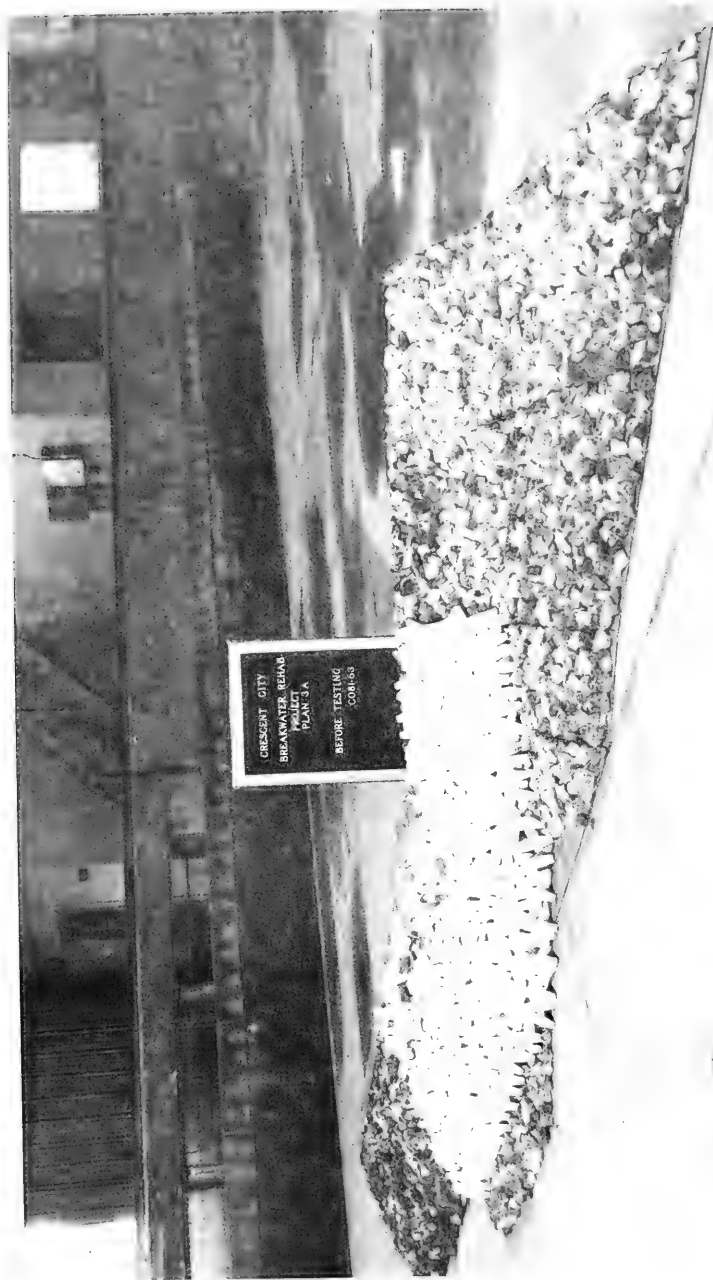


Photo 40. Seaward oblique view of Plan 3A before wave attack

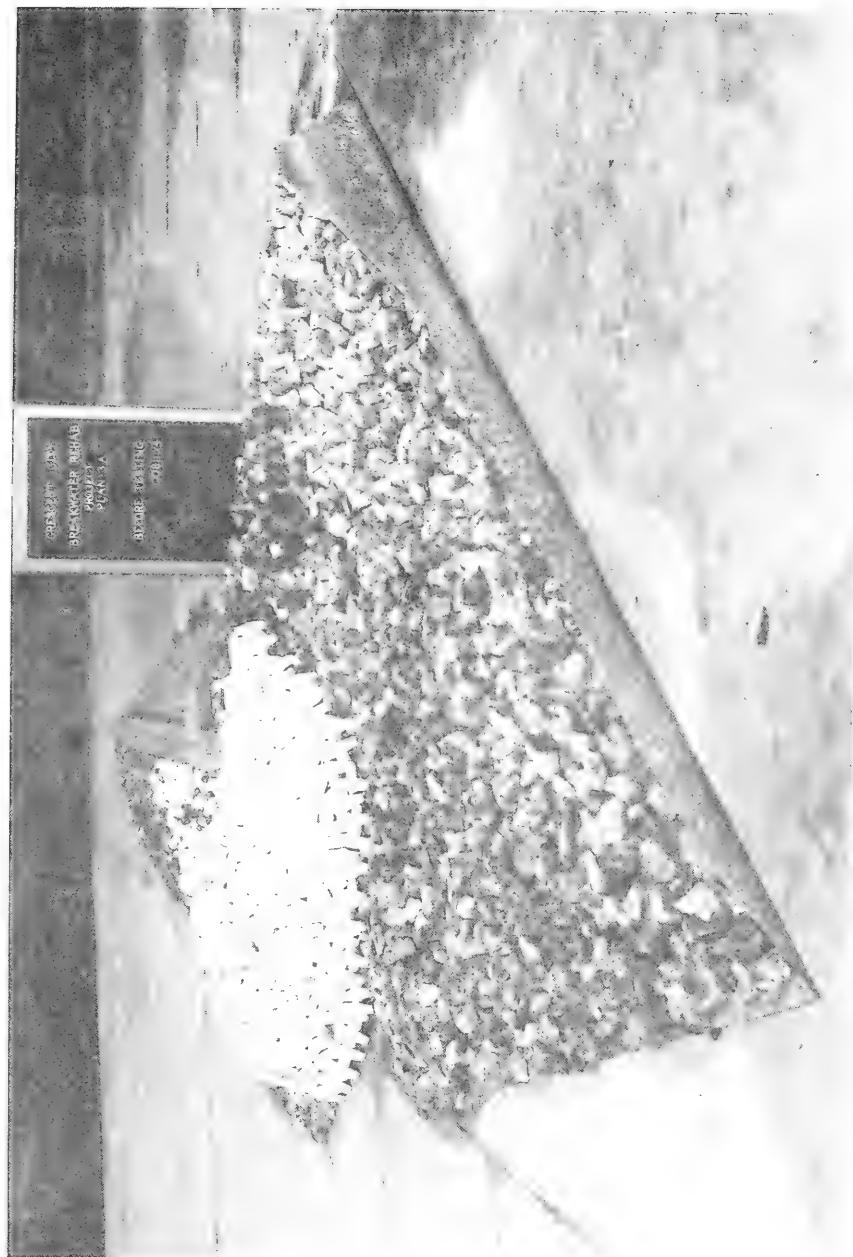


Photo 41. Seaward end view of Plan 3A before wave attack



Photo 42. Sea-side view of Plan 3A after completion of abbreviated hydrograph

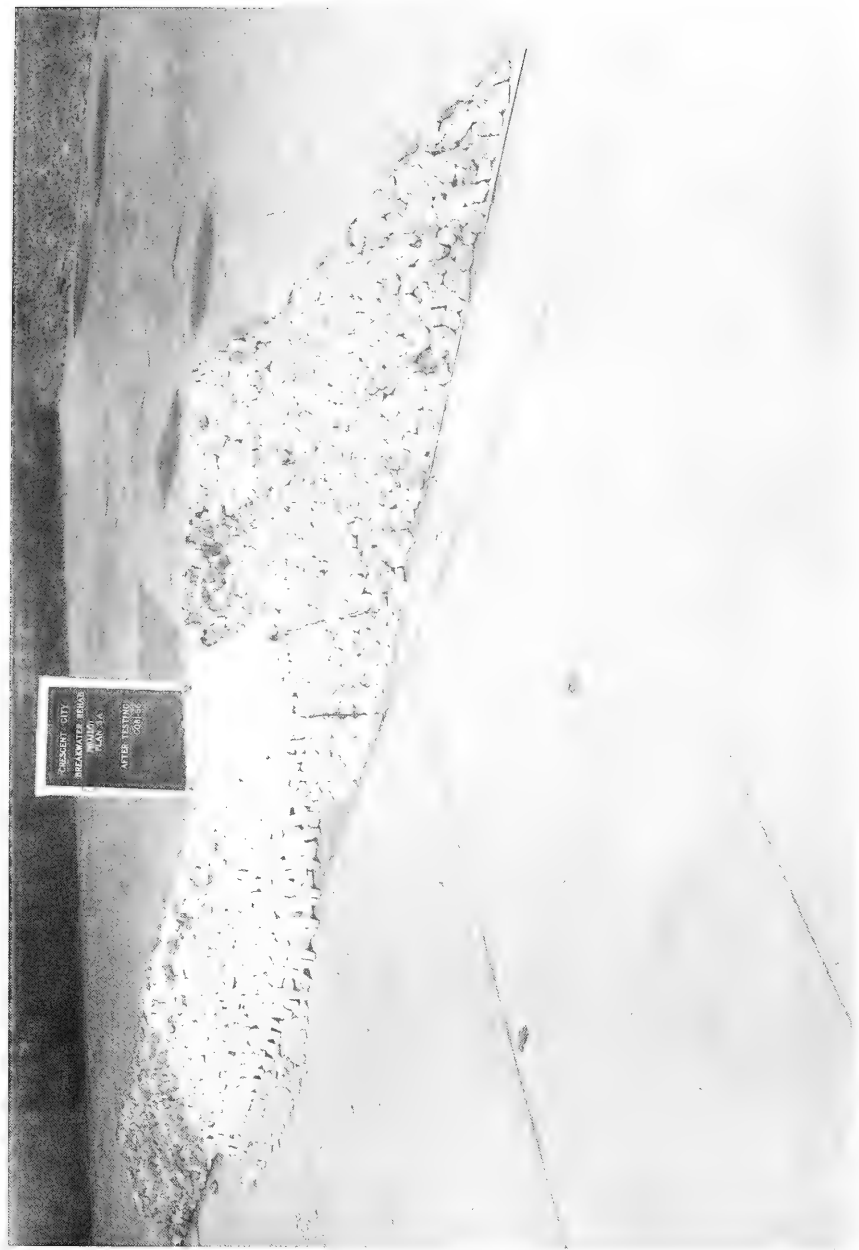


Photo 43. Seaward oblique view of Plan 3A after completion of abbreviated hydrograph



Photo 44. Seaward end view of Plan 3A after completion of abbreviated hydrograph

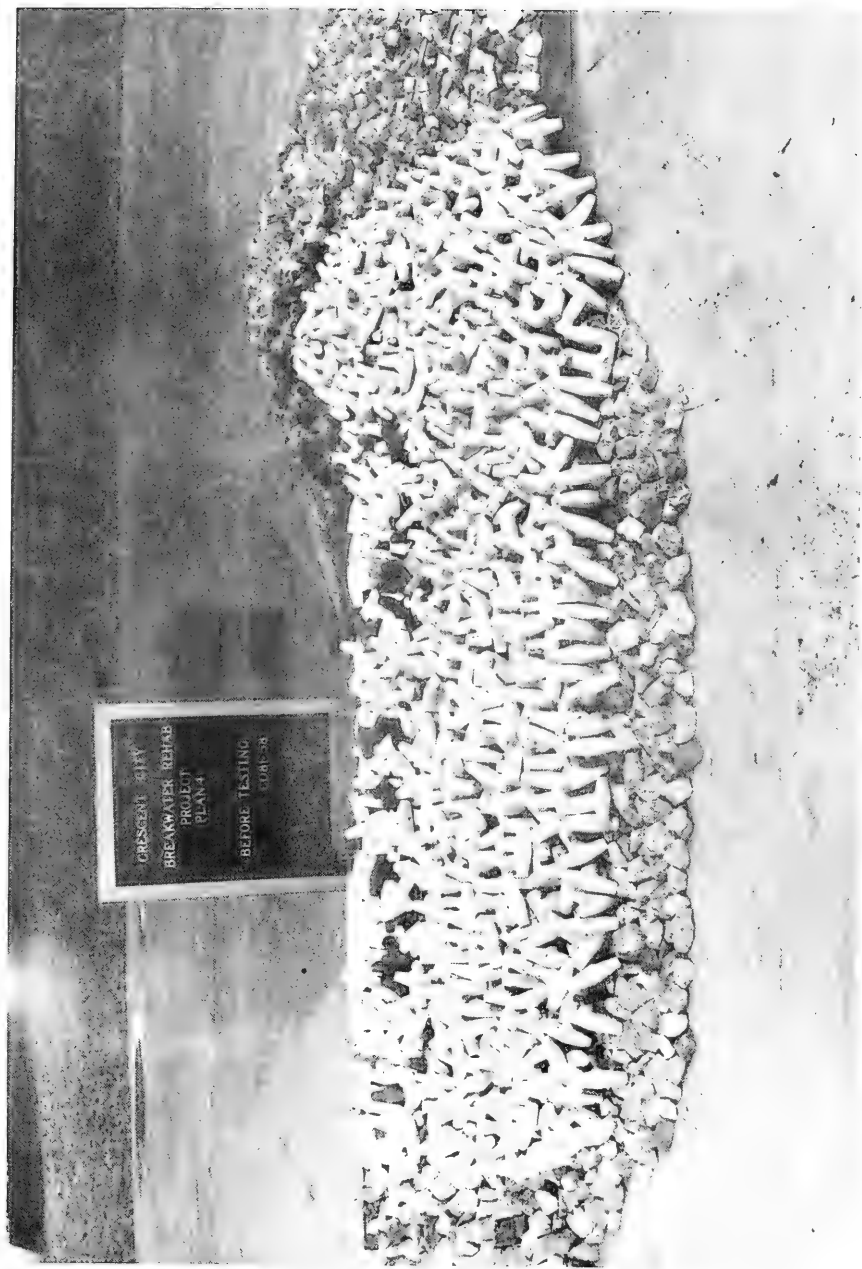


Photo 45. Sea-side view of Plan 4 before wave attack



Photo 46. Seaward oblique view of Plan 4 before wave attack



Photo 47. Seaward end view of Plan 4 before wave attack



Photo 48. Sea-side view of Plan 4 after completion of abbreviated hydrograph



Photo 49. Seaward oblique view of Plan 4 after completion of abbreviated hydrograph

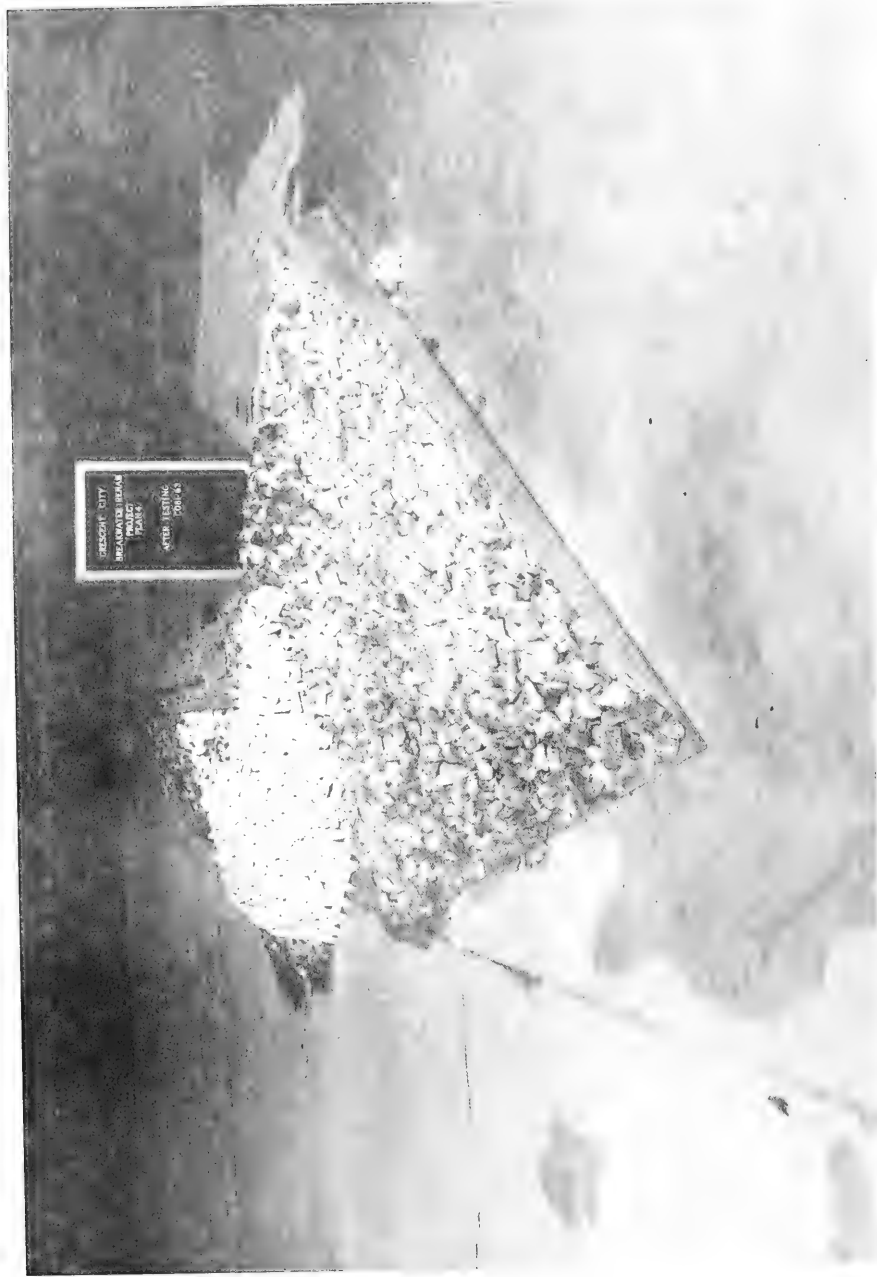


Photo 50. Seaward end view of Plan 4 after completion of abbreviated hydrograph

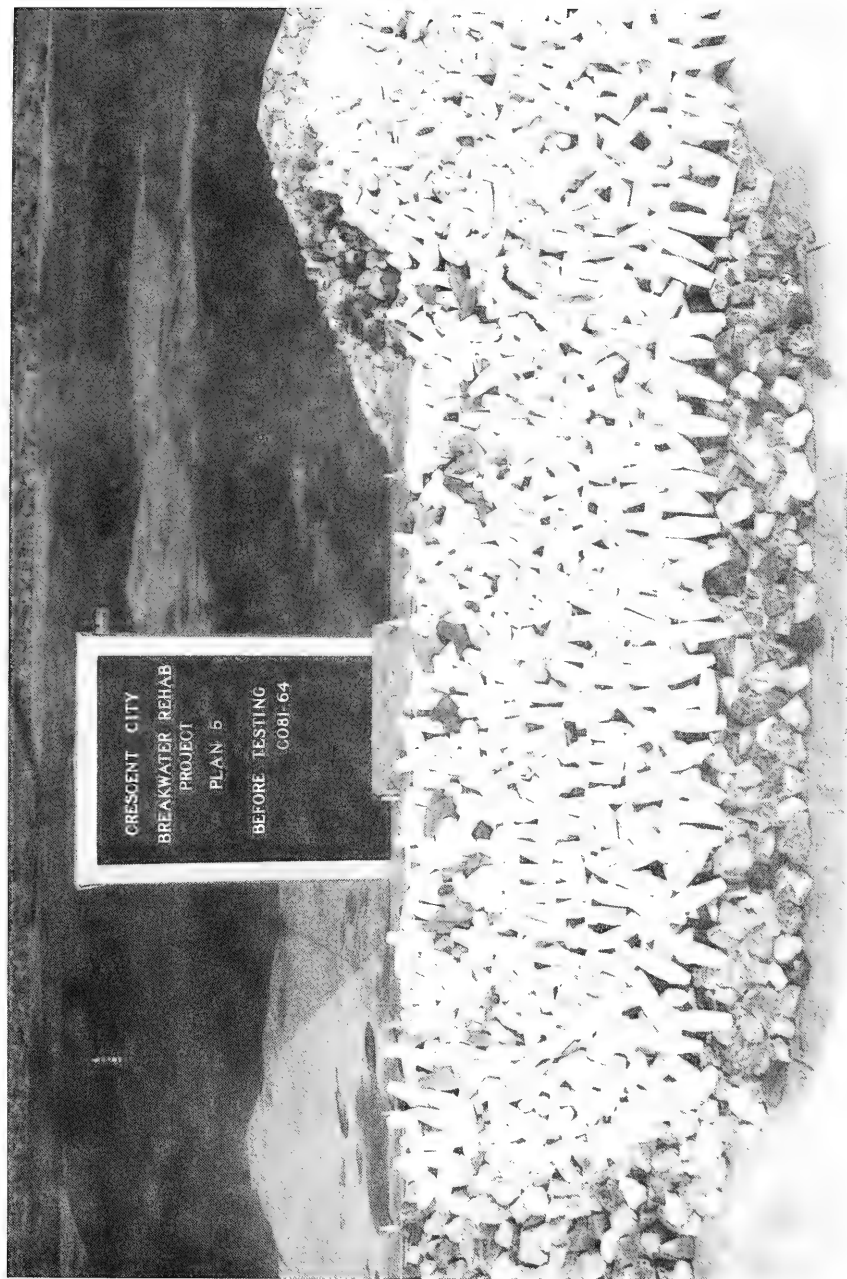


Photo 51. Sea-side view of Plan 5 before wave attack



Photo 52. Seaward oblique view of Plan 5 before wave attack



Photo 53. Seaward end view of Plan 5 before wave attack

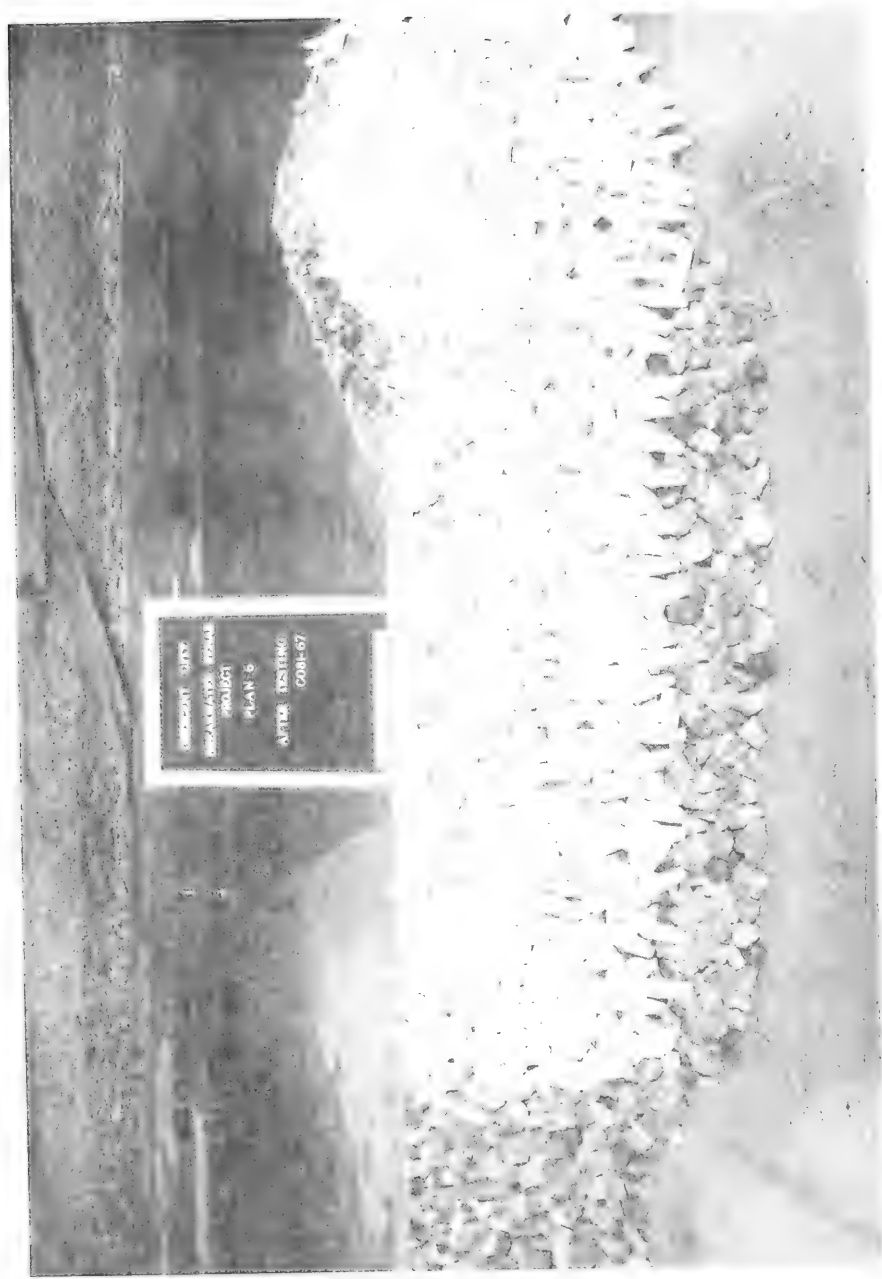


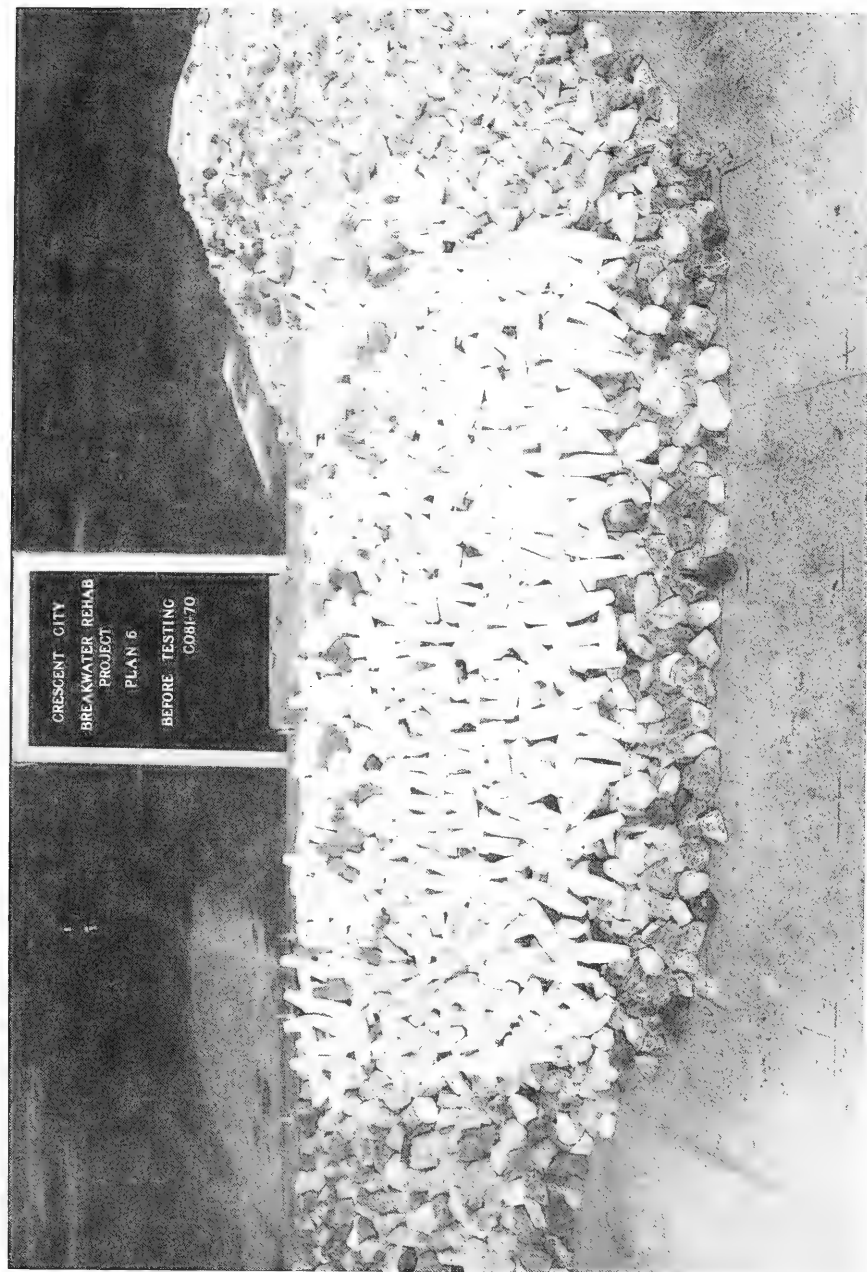
Photo 54. Sea-side view of Plan 5 after completion of abbreviated hydrograph



Photo 55. Seaward oblique view of Plan 5 after completion of abbreviated hydrograph



Photo 56. Seaward end view of Plan 5 after completion of abbreviated hydrograph



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Photo 57. Sea-side view of Plan 6 before wave attack



Photo 58. Seaward oblique view of Plan 6 before wave attack

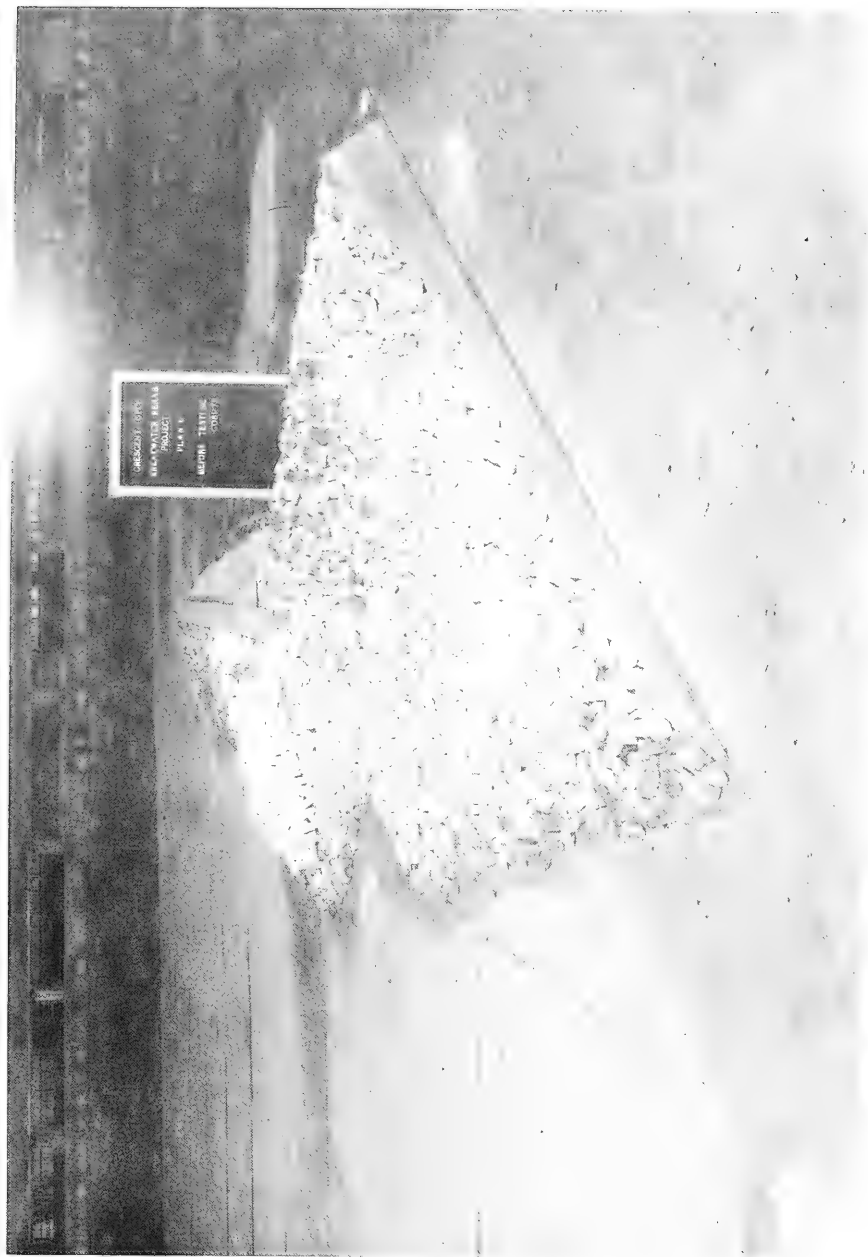
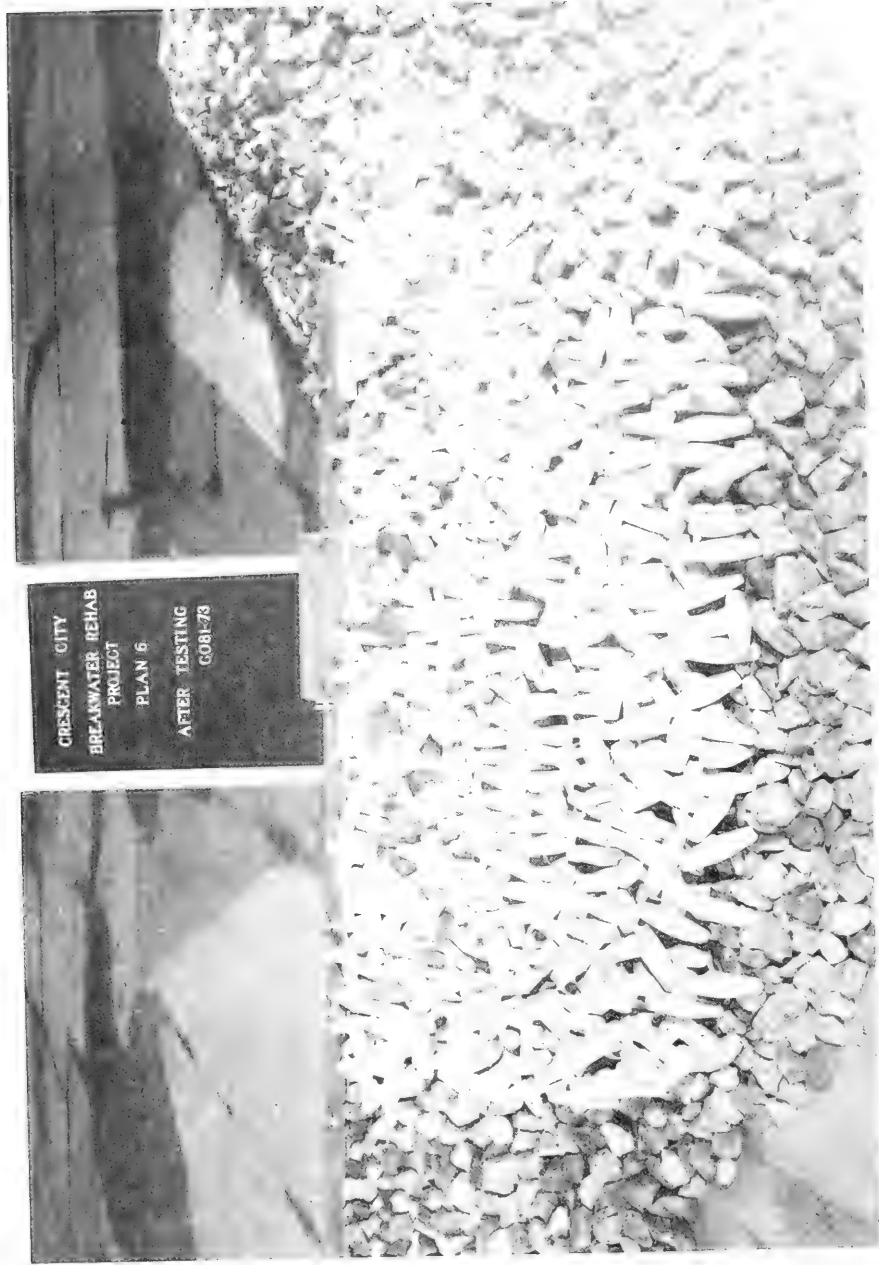


Photo 59. Seaward end view of Plan 6 before wave attack



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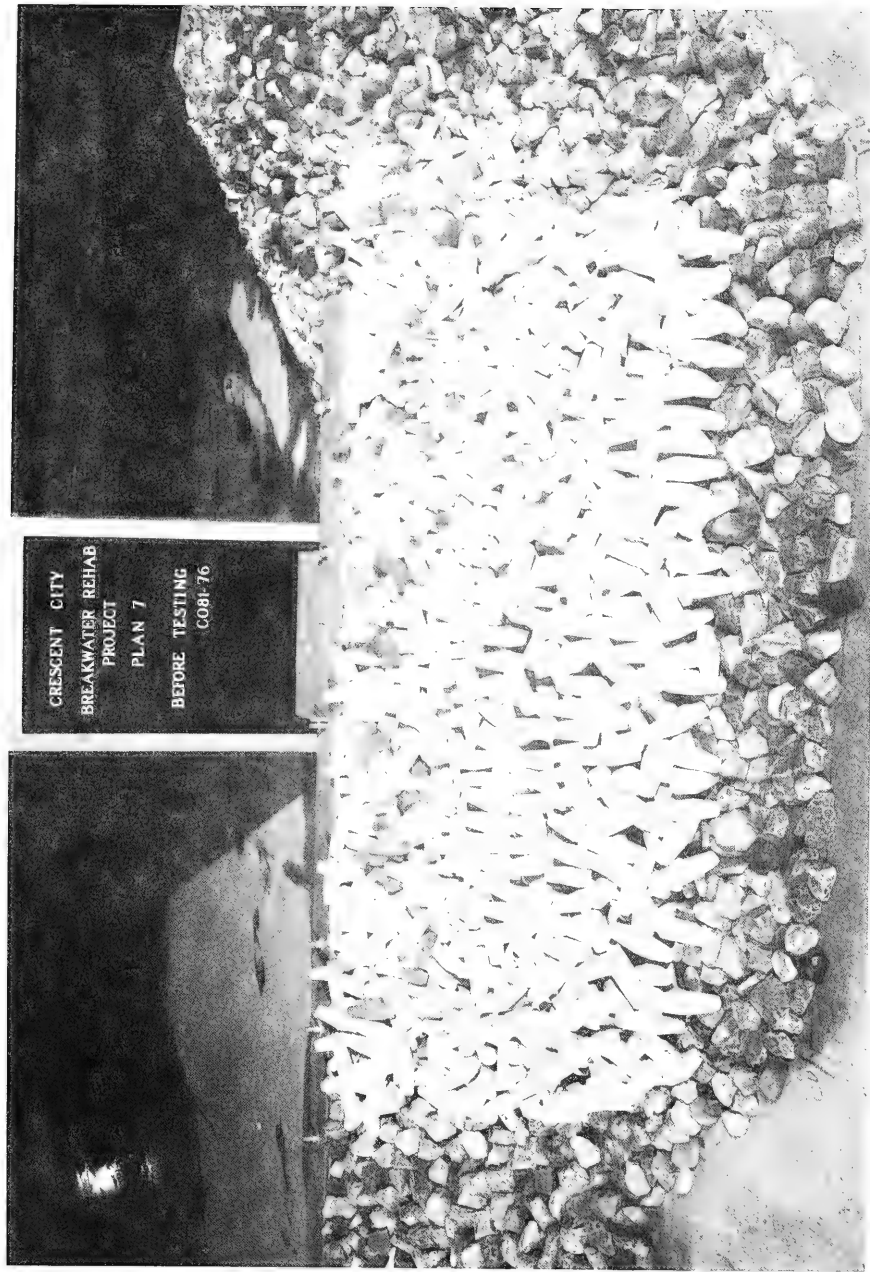
Photo 60. Sea-side view of Plan 6 after completion of abbreviated hydrograph



Photo 61. Seaward oblique view of Plan 6 after completion of abbreviated hydrograph



Photo 62. Seaward end view of Plan 6 after completion of abbreviated hydrograph



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Photo 63. Sea-side view of Plan 7 before wave attack



Photo 64. Seaward oblique view of Plan 7 before wave attack



Photo 65. Seaward end view of Plan 7 before wave attack

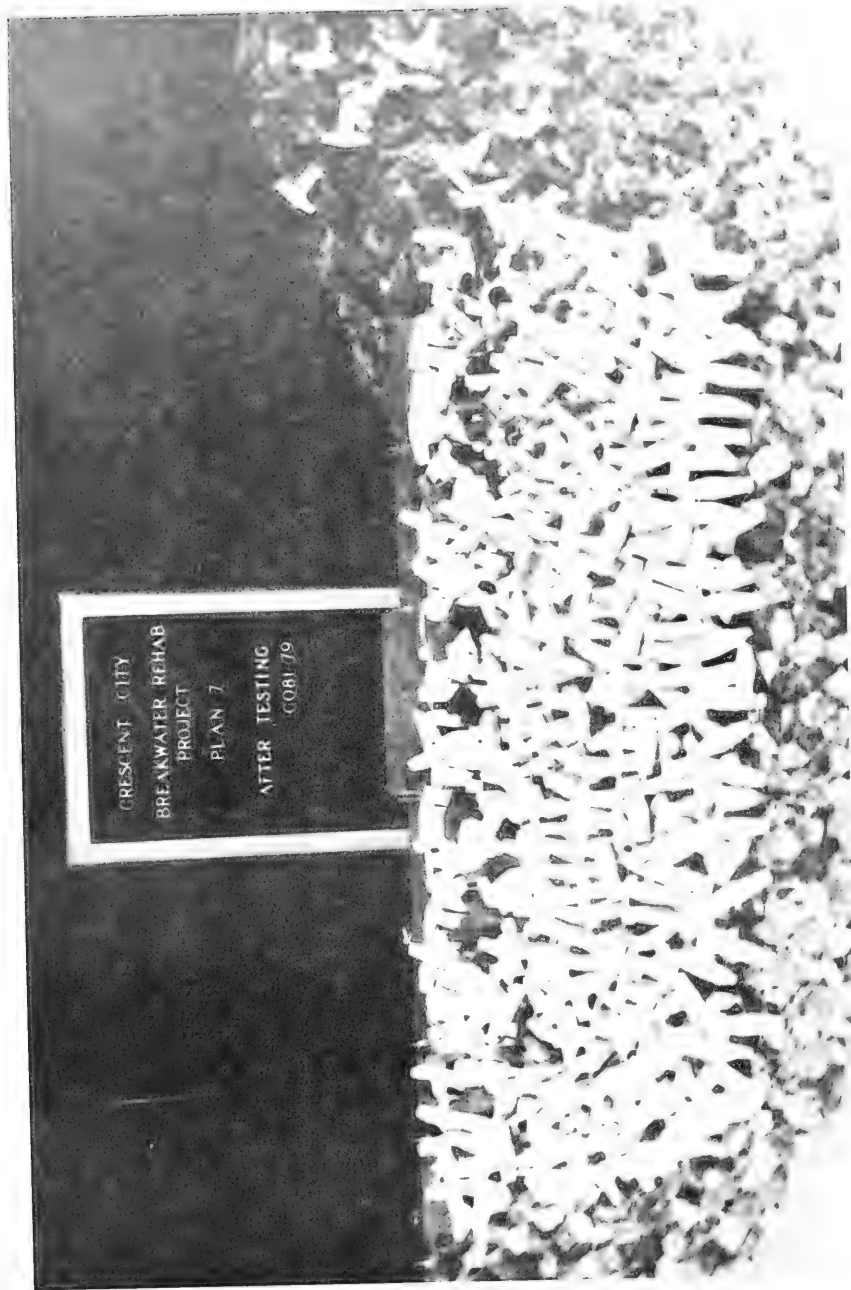


Photo 66. Sea-side view of Plan 7 after completion of abbreviated hydrograph



Photo 67. Seaward oblique view of Plan 7 after completion of abbreviated hydrograph



Photo 68. Seaward end view of Plan 7 after completion of abbreviated hydrograph

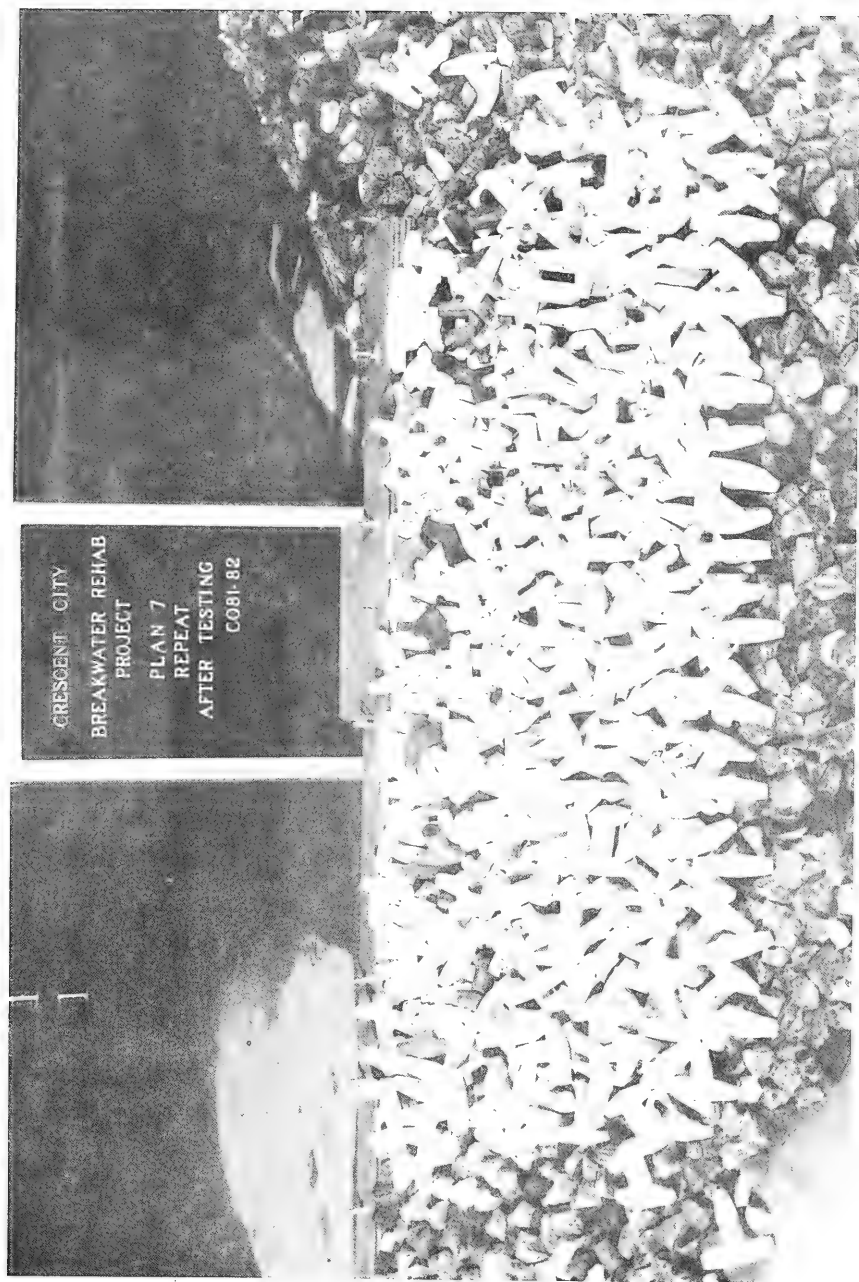


Photo 69. Sea-side view of Plan 7 after completion of abbreviated hydrograph

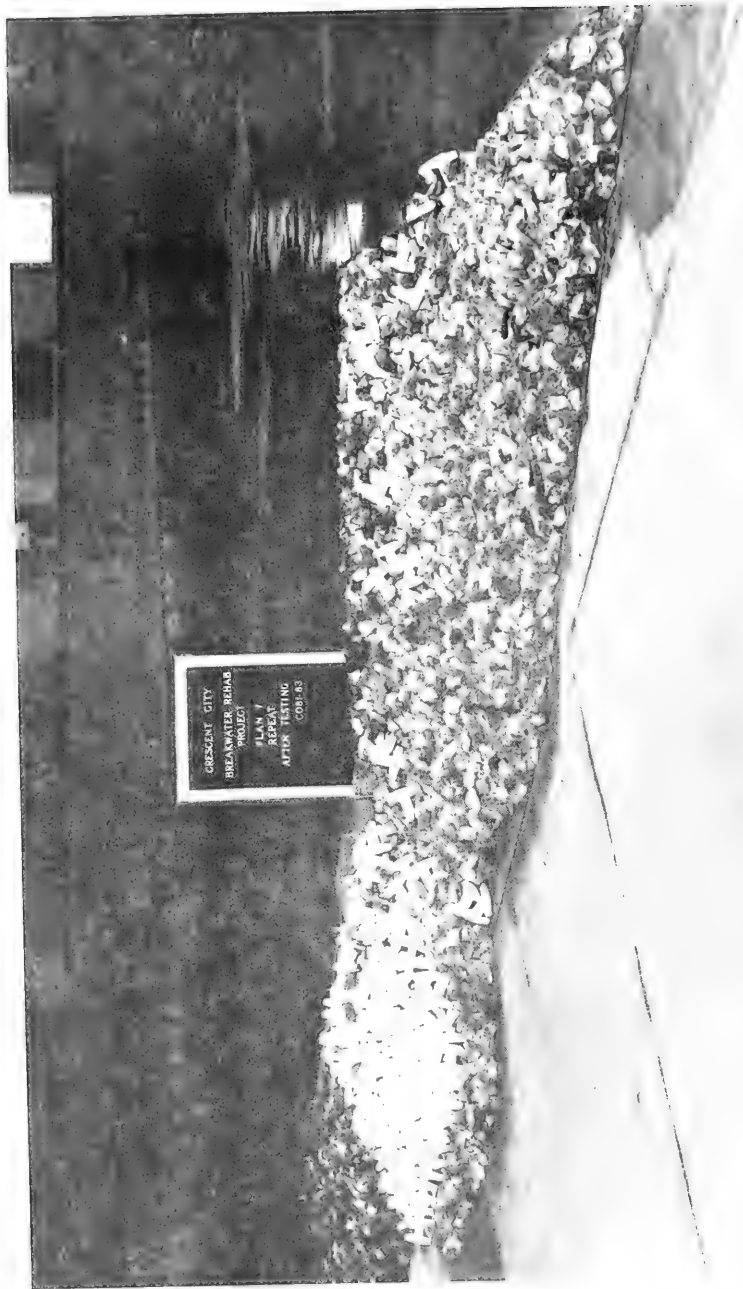


Photo 70. Seaward oblique view of Plan 7 repeat after completion of abbreviated hydrograph



Photo 71. Seaward end view of Plan 7 repeat after completion of abbreviated hydrograph

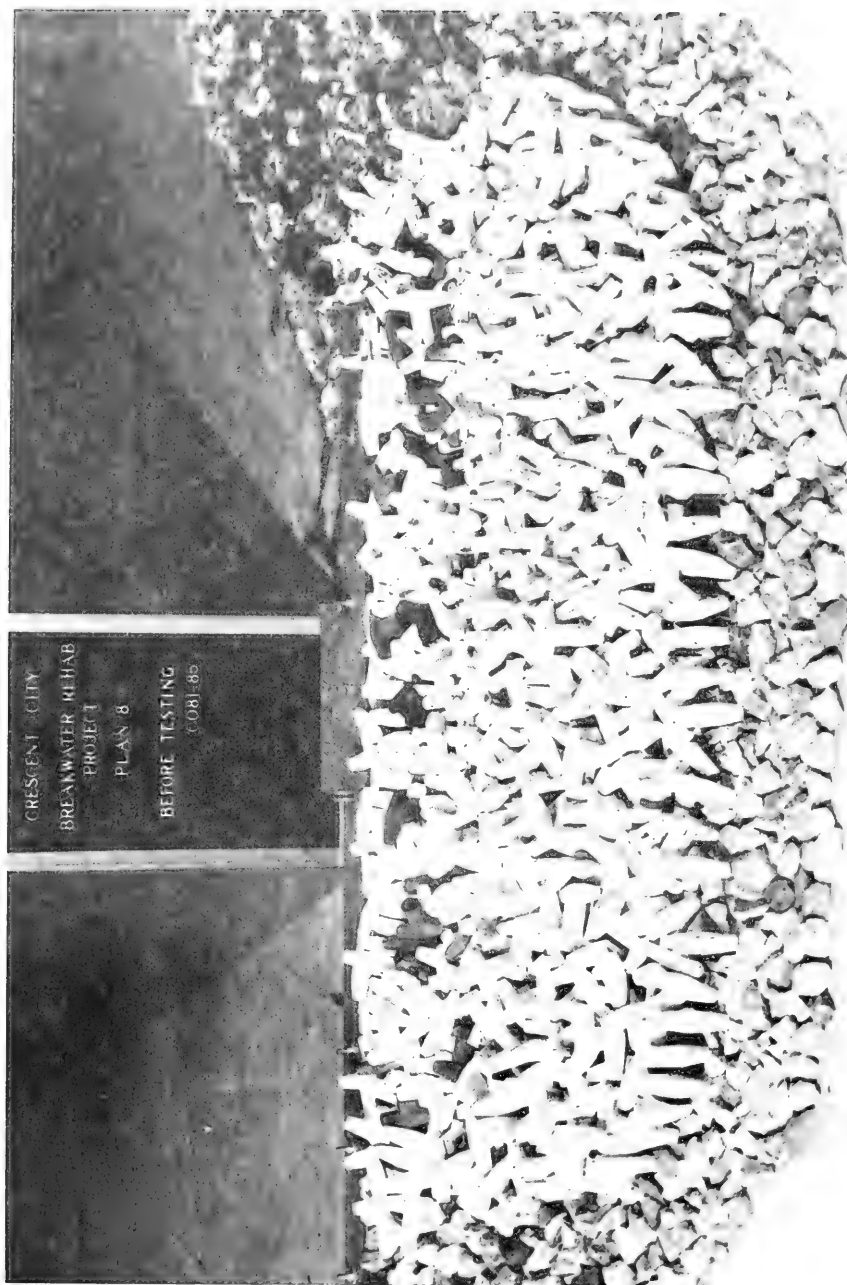


Photo 72. Sea-side view of Plan 8 before wave attack



Photo 73. Seaward oblique view of Plan 8 before wave attack

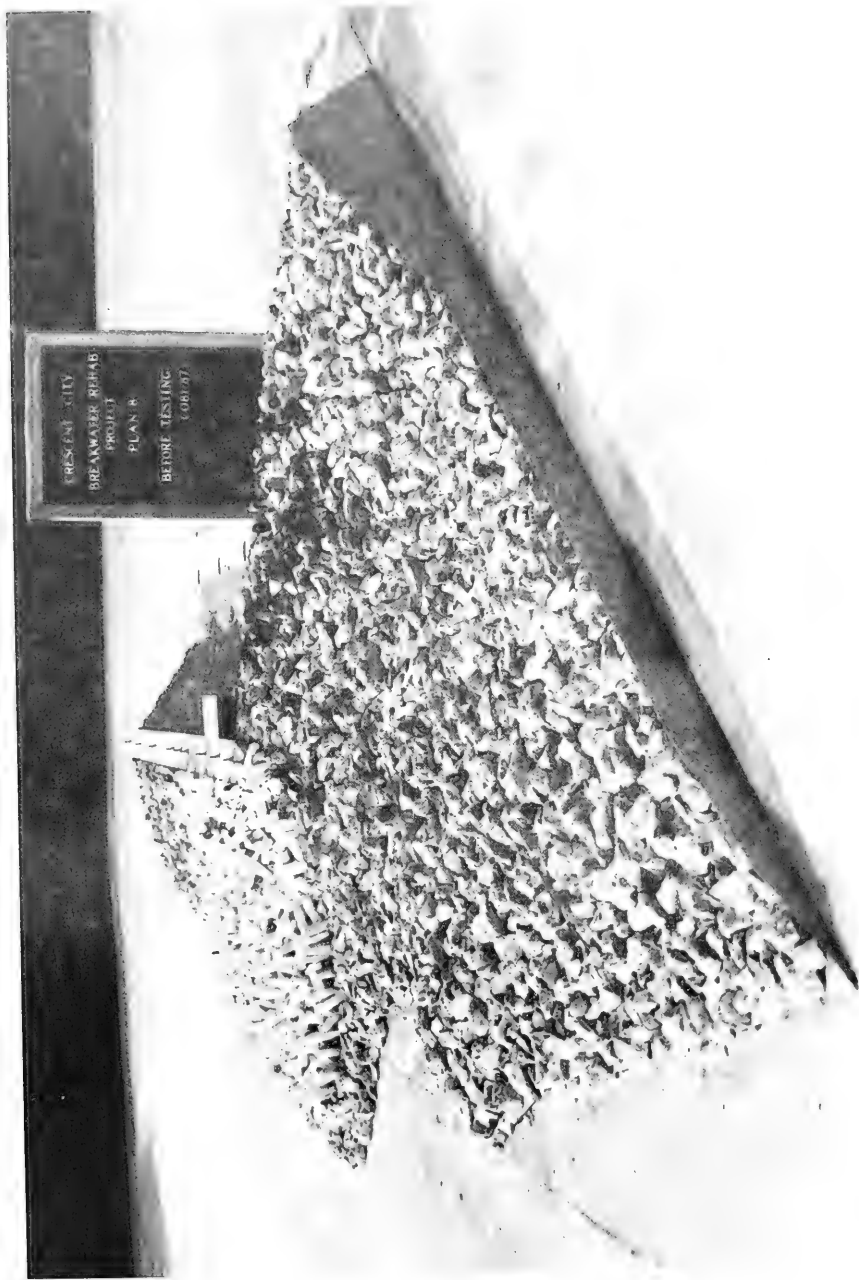


Photo 74. Seaward end view of Plan 8 before wave attack

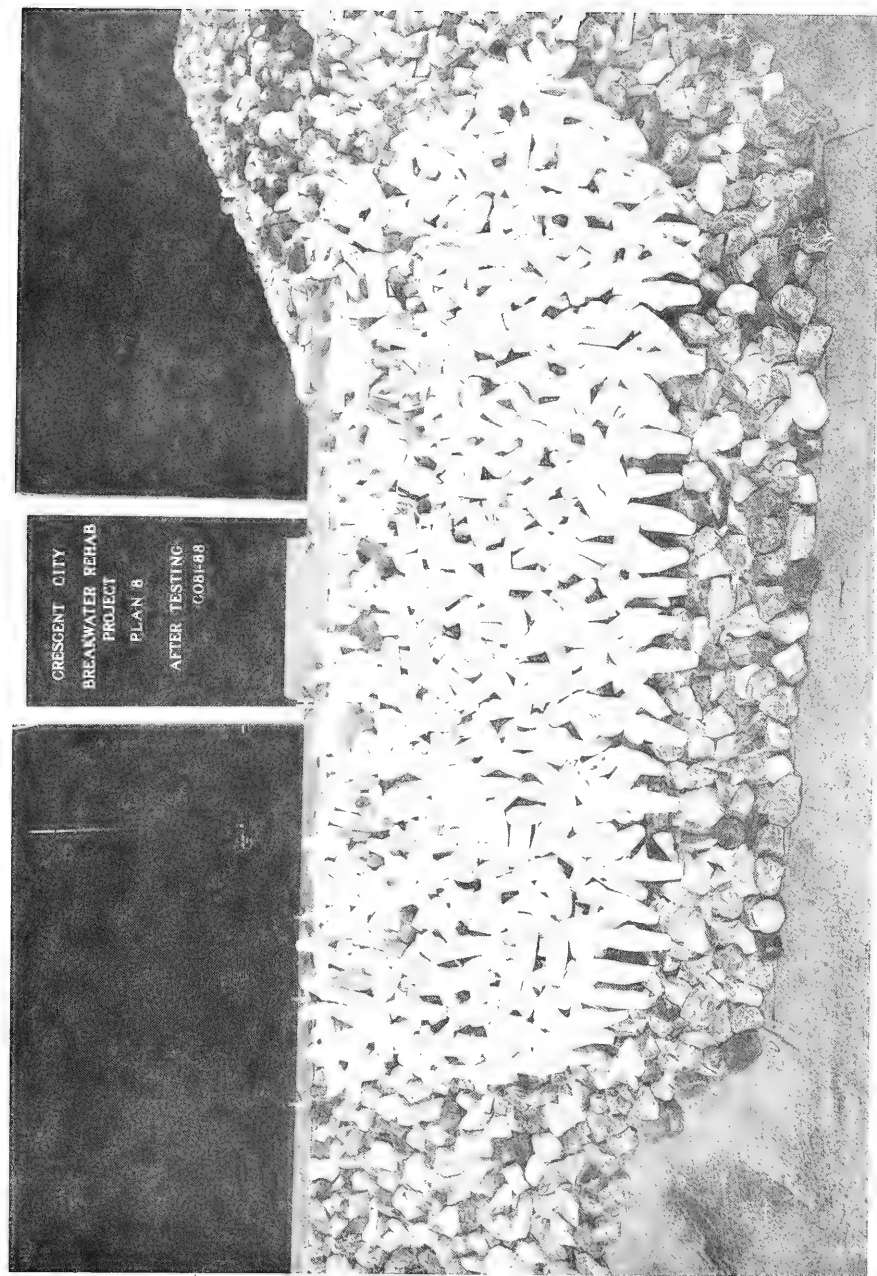


Photo 75. Sea-side view of Plan 8 after completion of abbreviated hydrograph

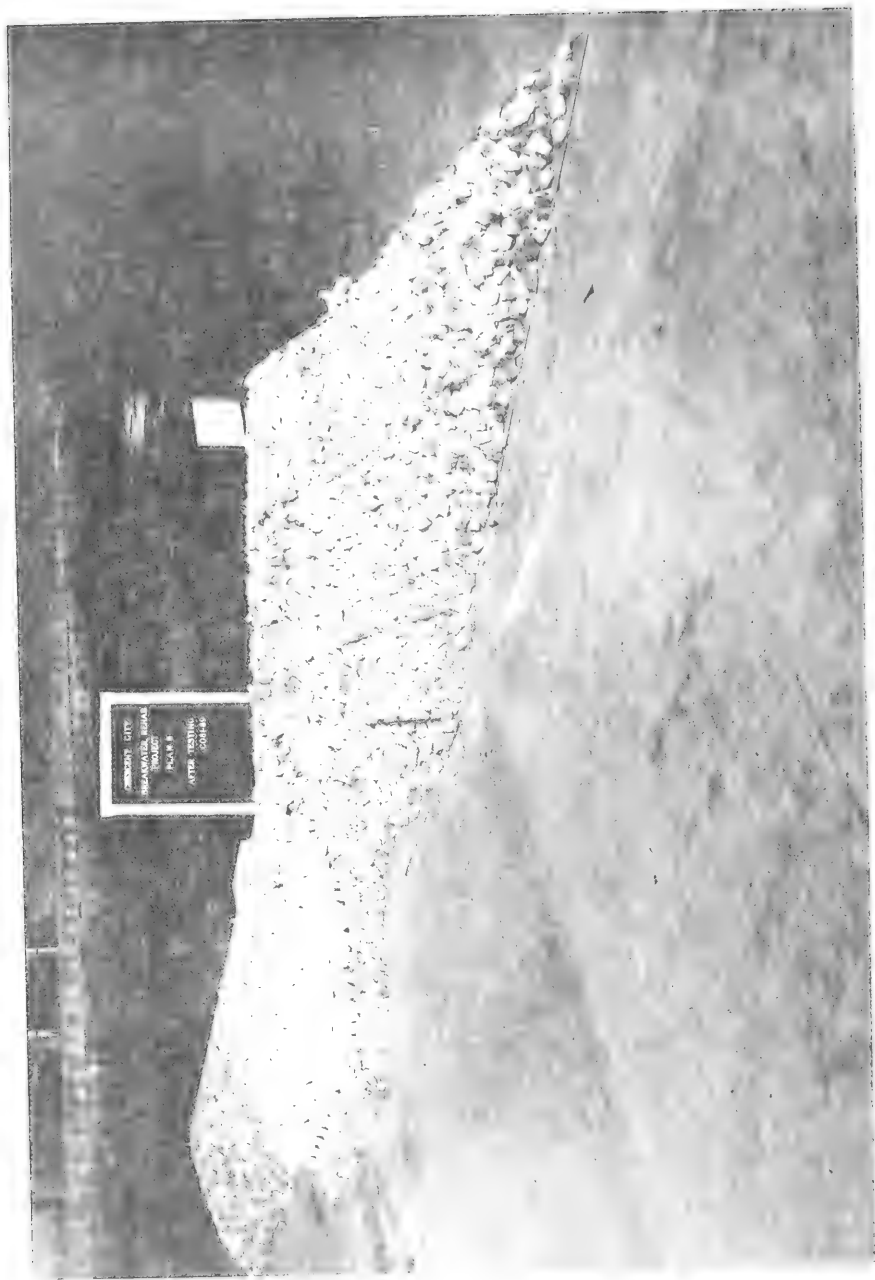
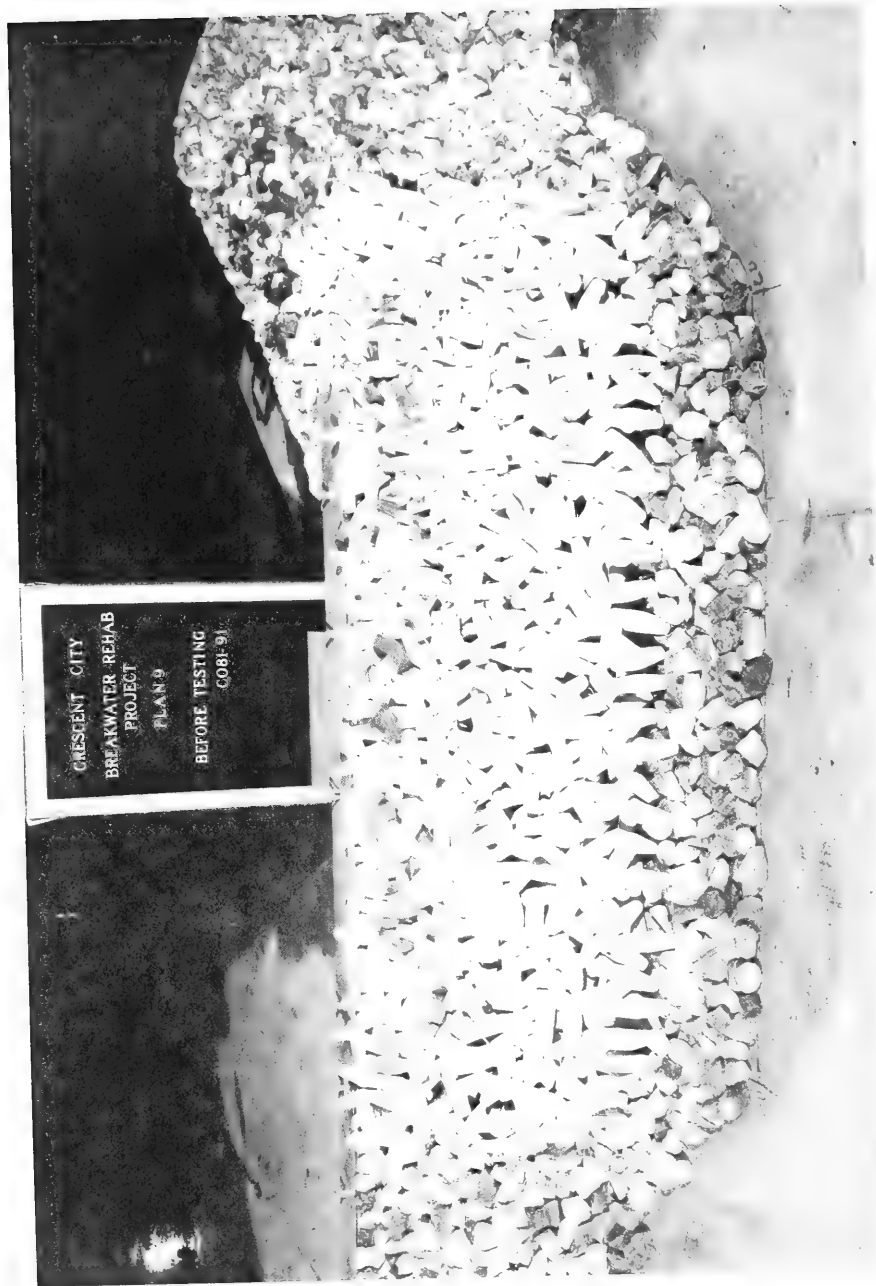


Photo 76. Seaward oblique view of Plan 8 after completion of abbreviated hydrograph



Photo 77. Seaward end view of Plan 8 after completion of abbreviated hydrograph



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Photo 78. Sea-side view of Plan 9 before wave attack



Photo 79. Seaward oblique view of Plan 9 before wave attack



Photo 80. Seaward end view of Plan 9 before wave attack



Photo 81. Sea-side view of Plan 9 after completion of abbreviated hydrograph

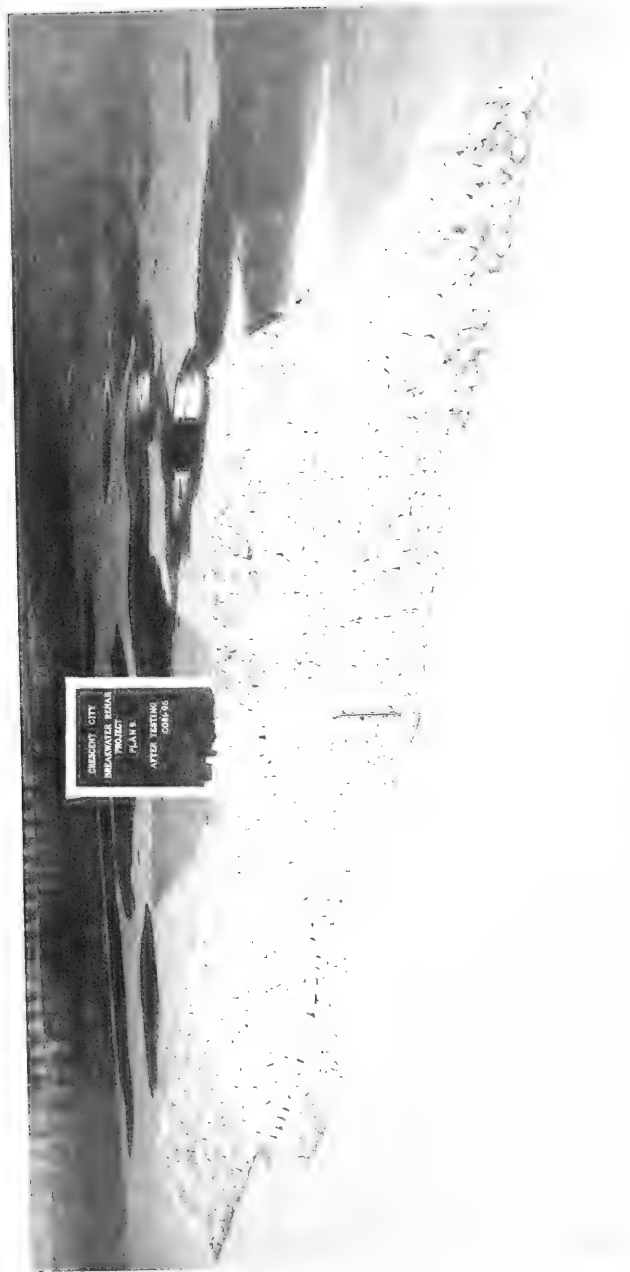


Photo 82. Seaward oblique view of Plan 9 after completion of abbreviated hydrograph



Photo 83. Seaward end view of Plan 9 after completion of abbreviated hydrograph



Photo 84. Sea-side view of Plan 10 before wave attack



Photo 85. Seaward oblique view of Plan 10 before wave attack



Photo 86. Seaward end view of Plan 10 before wave attack

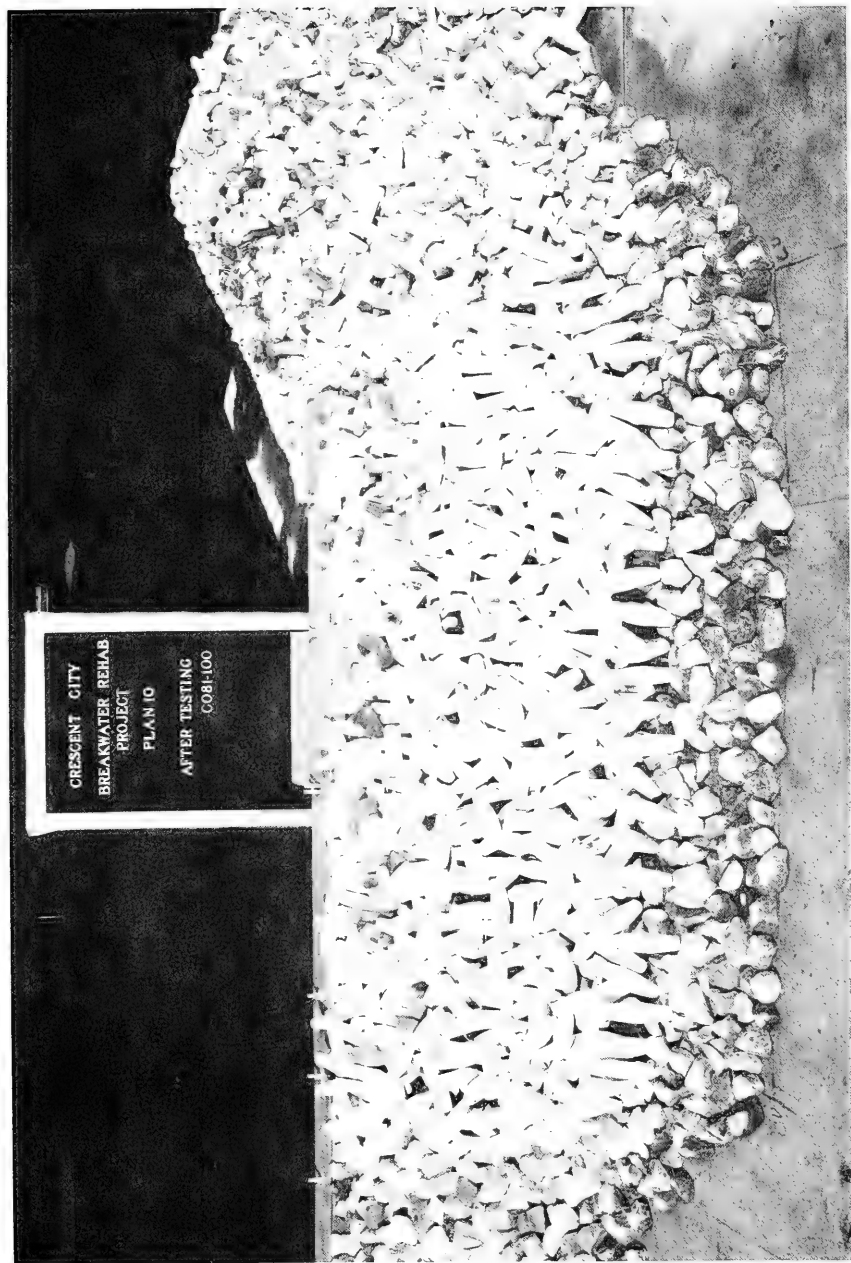


Photo 87. Sea-side view of Plan 10 after completion of abbreviated hydrograph



Photo 88. Seaward oblique view of Plan 10 after completion of abbreviated hydrograph



Photo 89. Seaward end view of Plan 10 after completion of abbreviated hydrograph

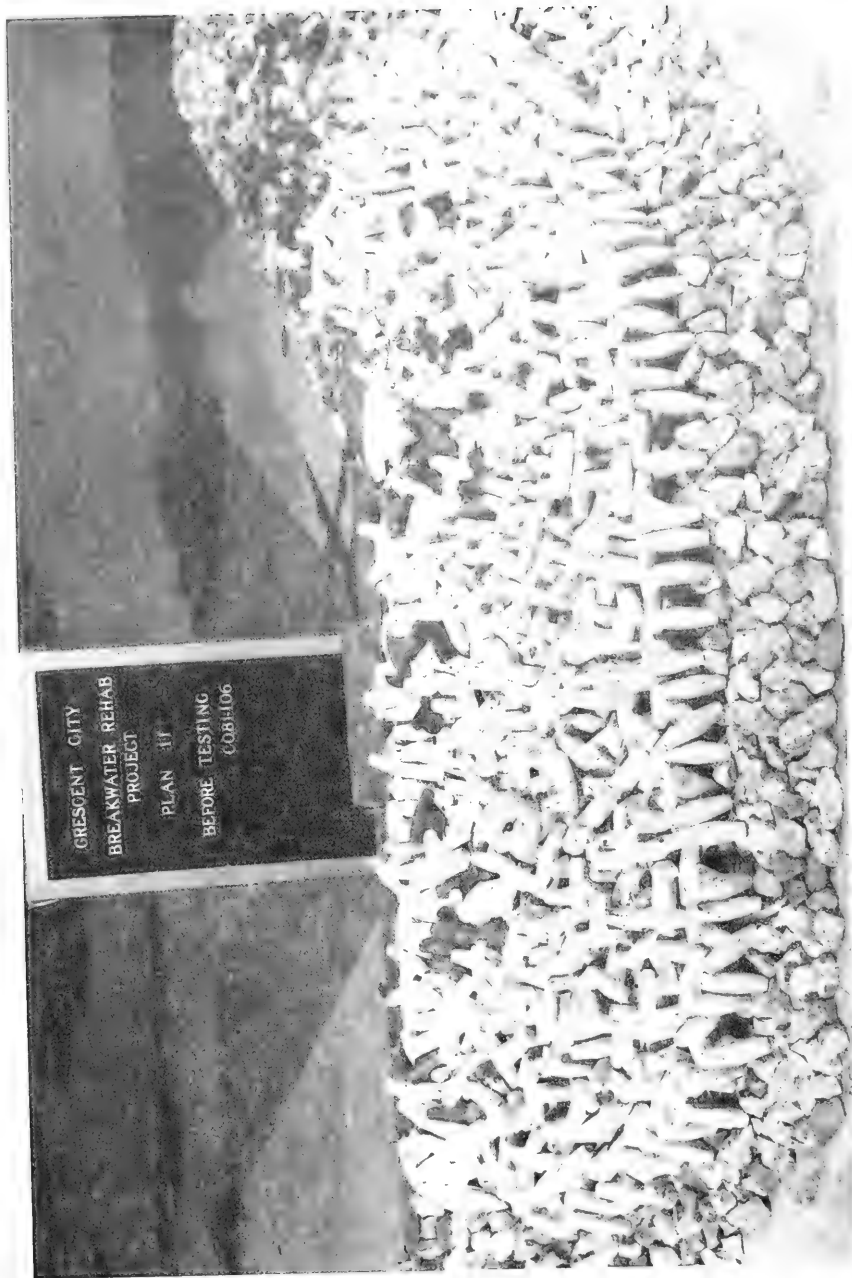


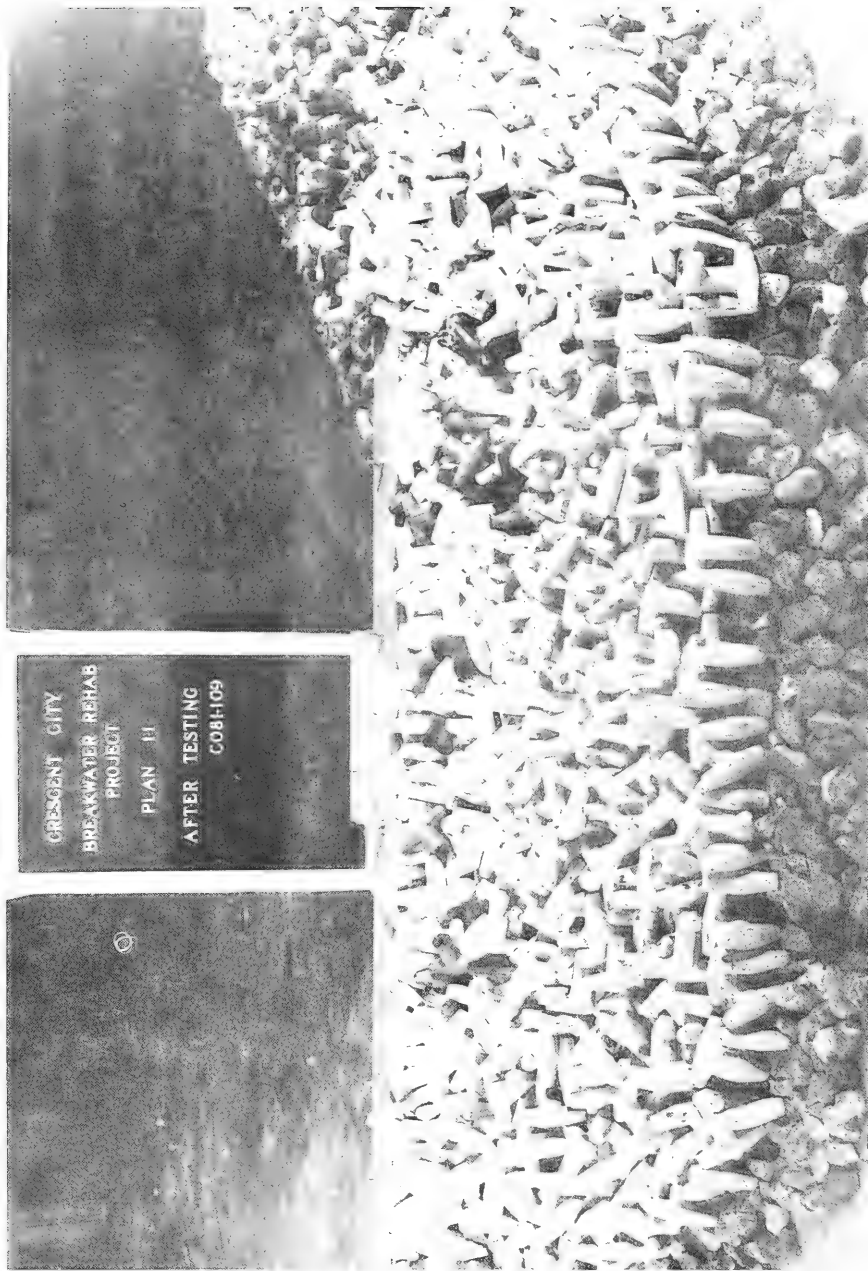
Photo 90. Sea-side view of Plan 11 before wave attack



Photo 91. Seaward oblique view of Plan 11 before wave attack



Photo 92. Seaward end view of Plan 11 before wave attack



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Photo 93. Sea-side view of Plan 11 after completion of abbreviated hydrograph



Photo 94. Seaward oblique view of Plan 11 after completion of abbreviated hydrograph



Photo 95. Seaward end view of Plan 11 after completion of abbreviated hydrograph

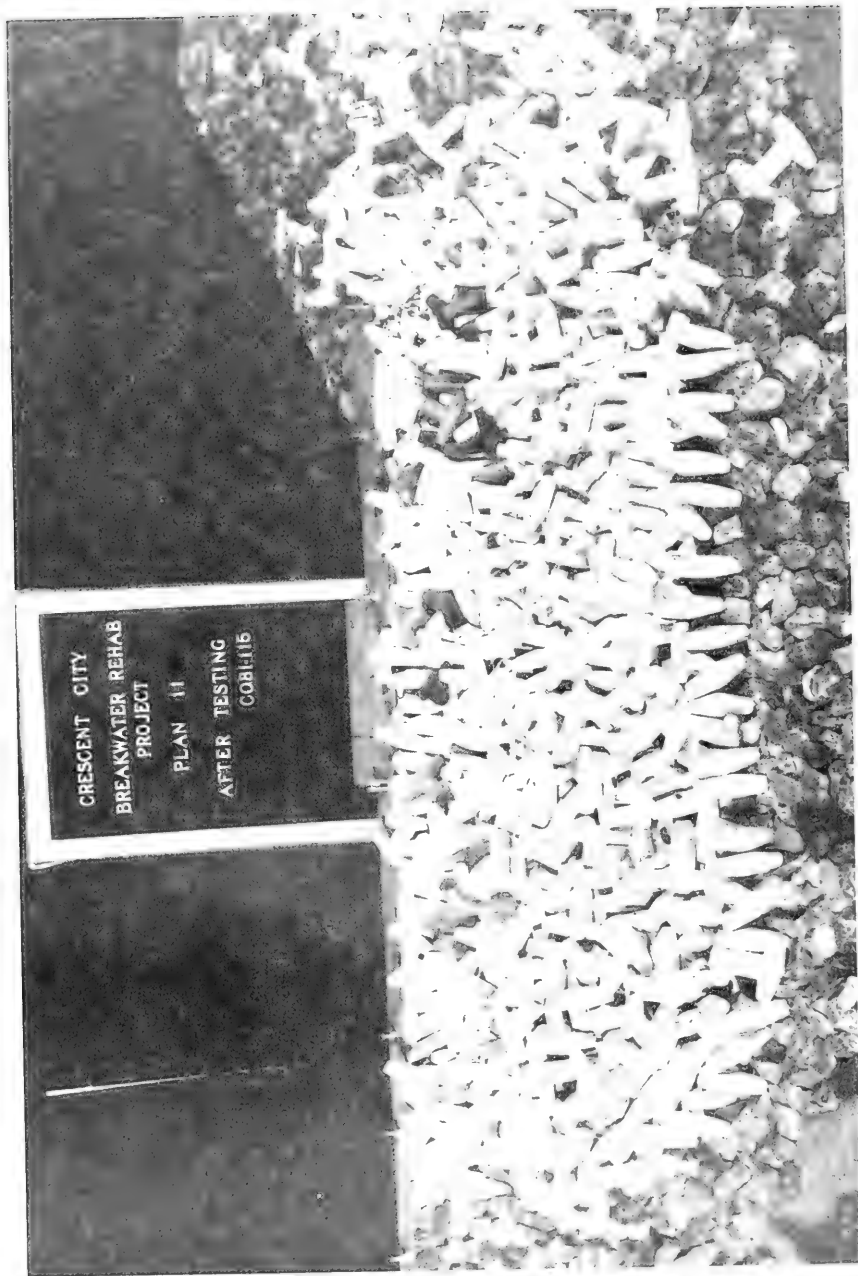


Photo 96. Sea-side view of Plan 11 repeat after completion of abbreviated hydrograph



Photo 97. Seaward oblique view of Plan 11 repeat after completion of abbreviated hydrograph

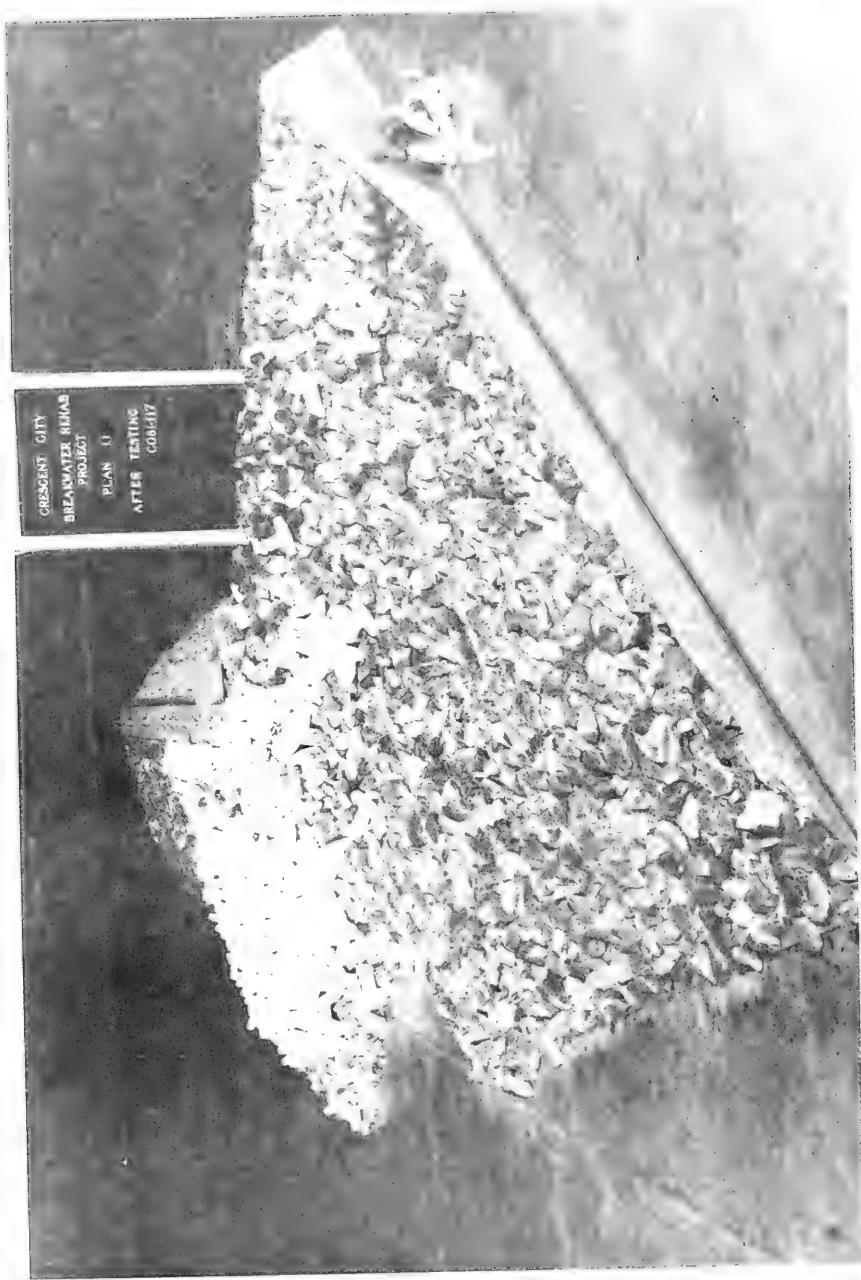


Photo 98. Seaward end view of Plan 11 repeat after completion of abbreviated hydrograph

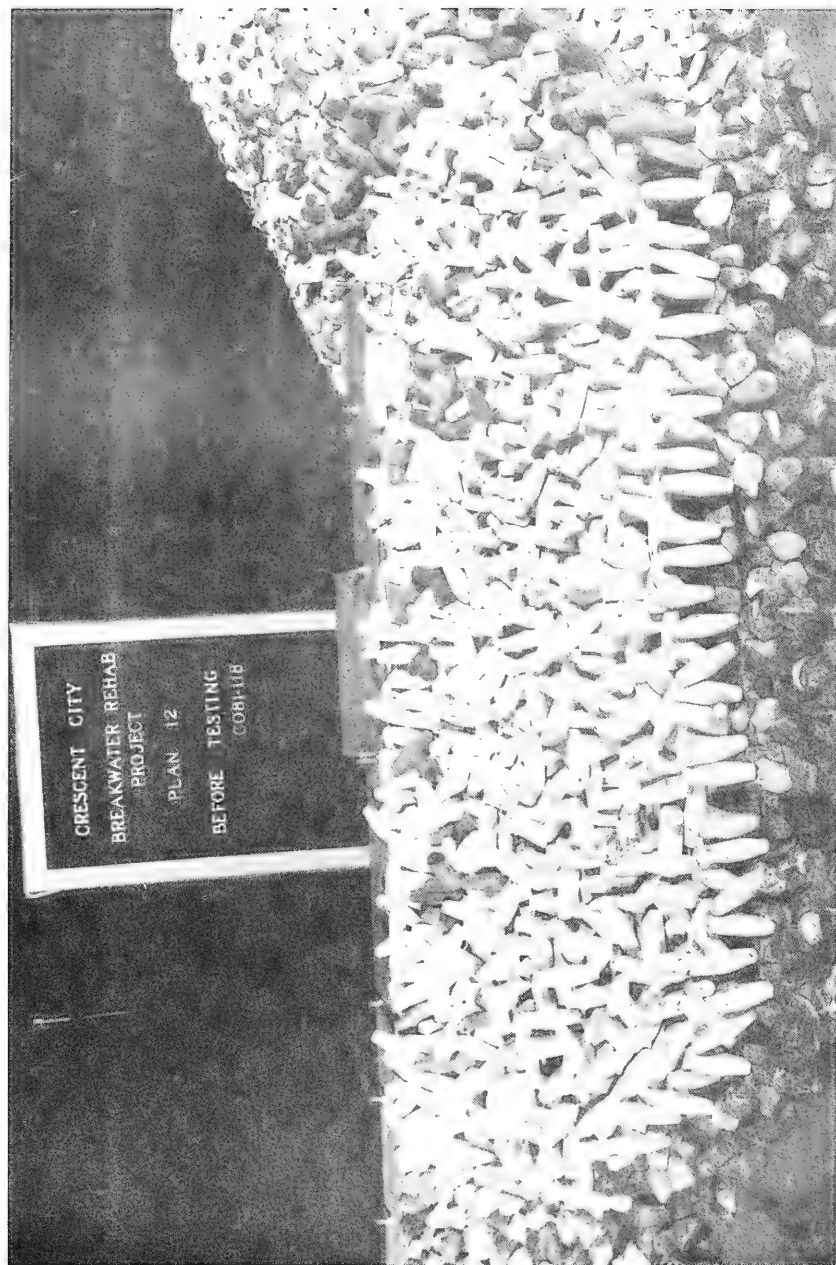


Photo 99. Sea-side view of Plan 12 before wave attack

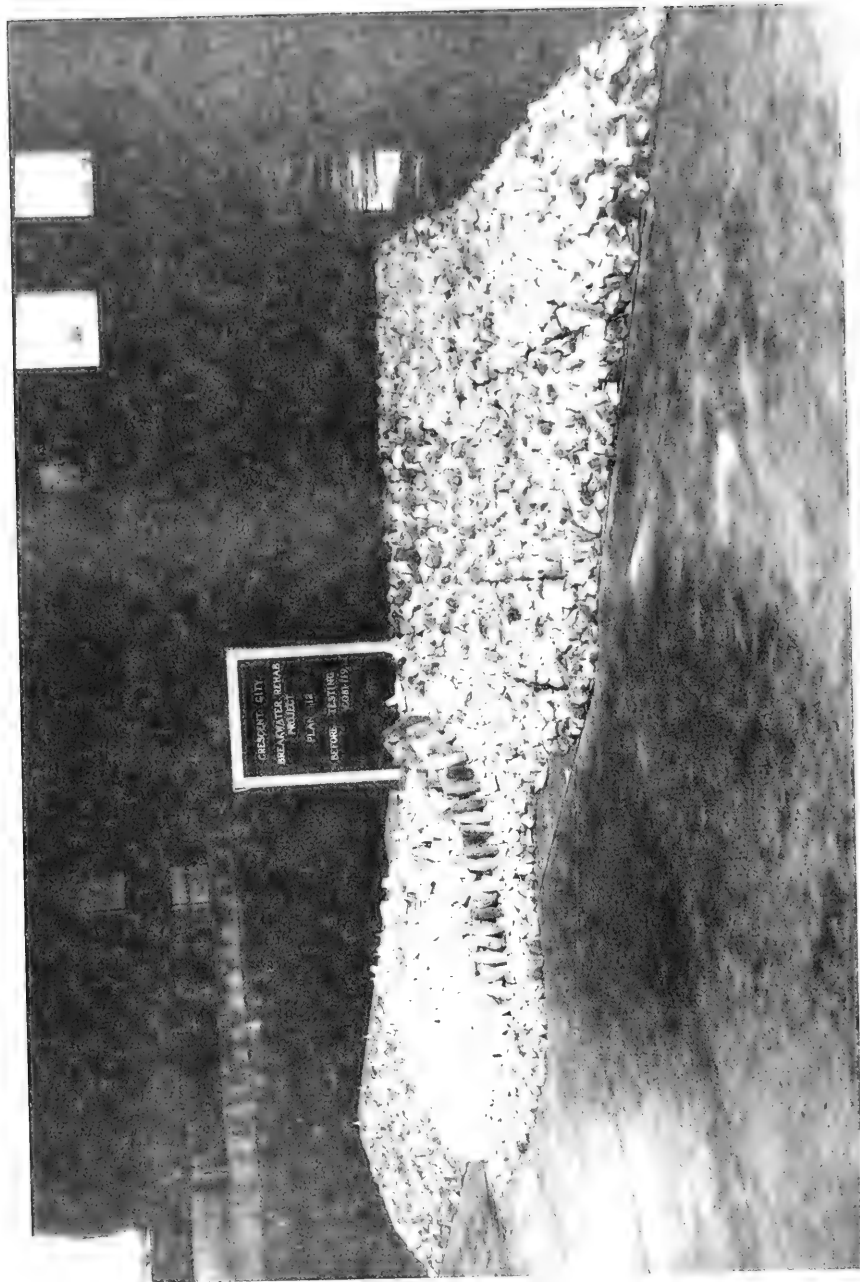


Photo 100. Seaward oblique view of Plan 12 before wave attack

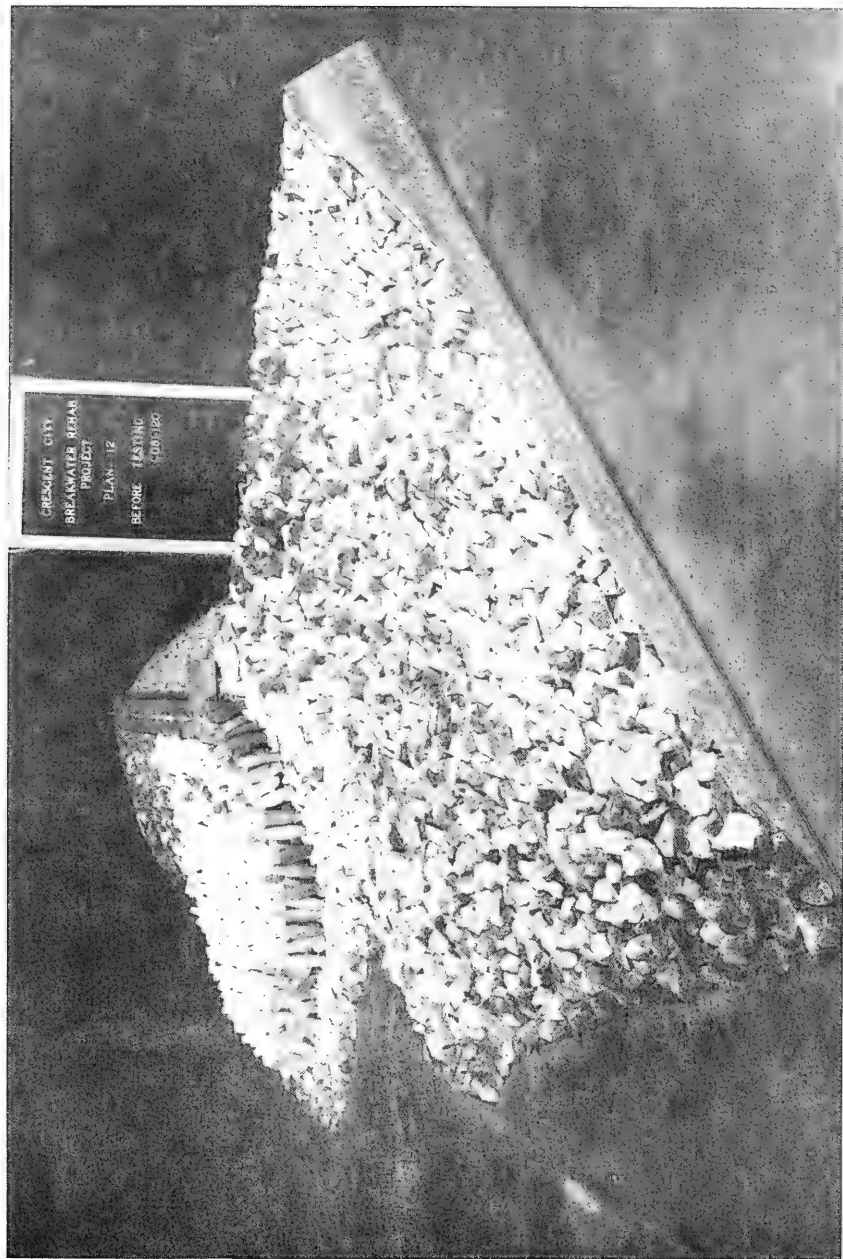


Photo 101. Seaward end view of Plan 12 before wave attack

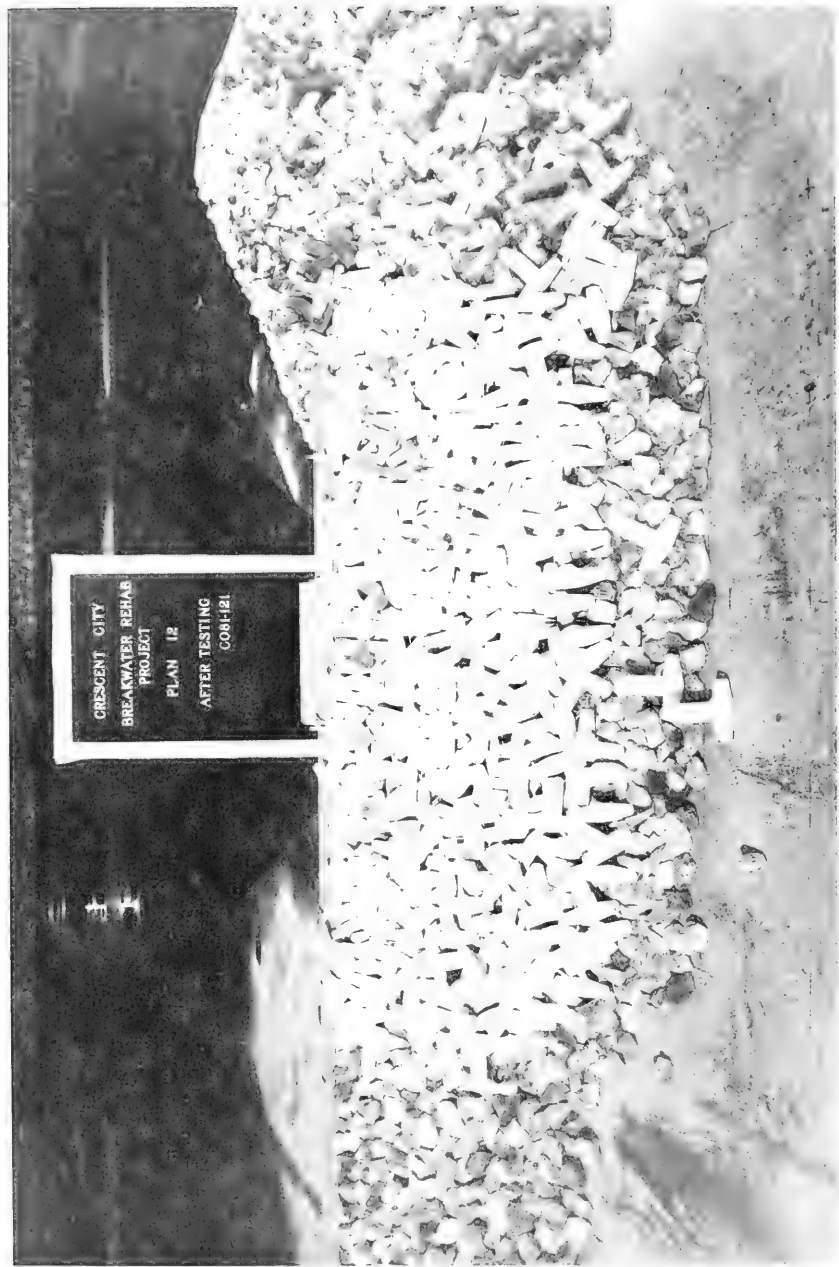


Photo 102. Sea-side view of Plan 12 after completion of abbreviated hydrograph



Photo 103. Seaward oblique view of Plan 12 after completion of abbreviated hydrograph



Photo 104. Seaward end view of Plan 12 after completion of abbreviated hydrograph

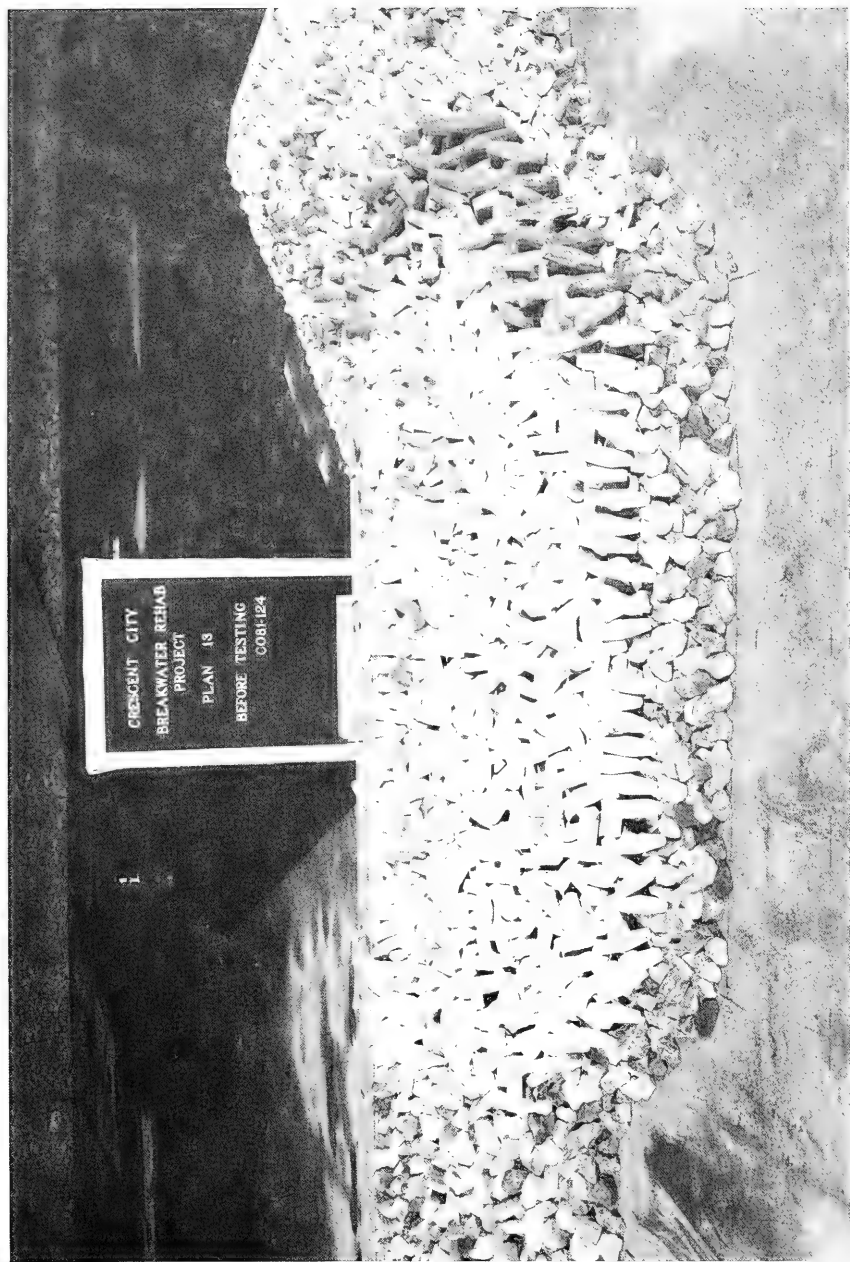


Photo 105. Sea-side view of Plan 13 before wave attack



Photo 106. Seaward oblique view of Plan 13 before wave attack



Photo 107. Seaward end view of Plan 13 before wave attack



Photo 108. Sea-side view of Plan 13 after completion of abbreviated hydrograph



Photo 109. Seaward oblique view of Plan 13 after completion of abbreviated hydrograph



Photo 110. Seaward end view of Plan 13 after completion of abbreviated hydrograph

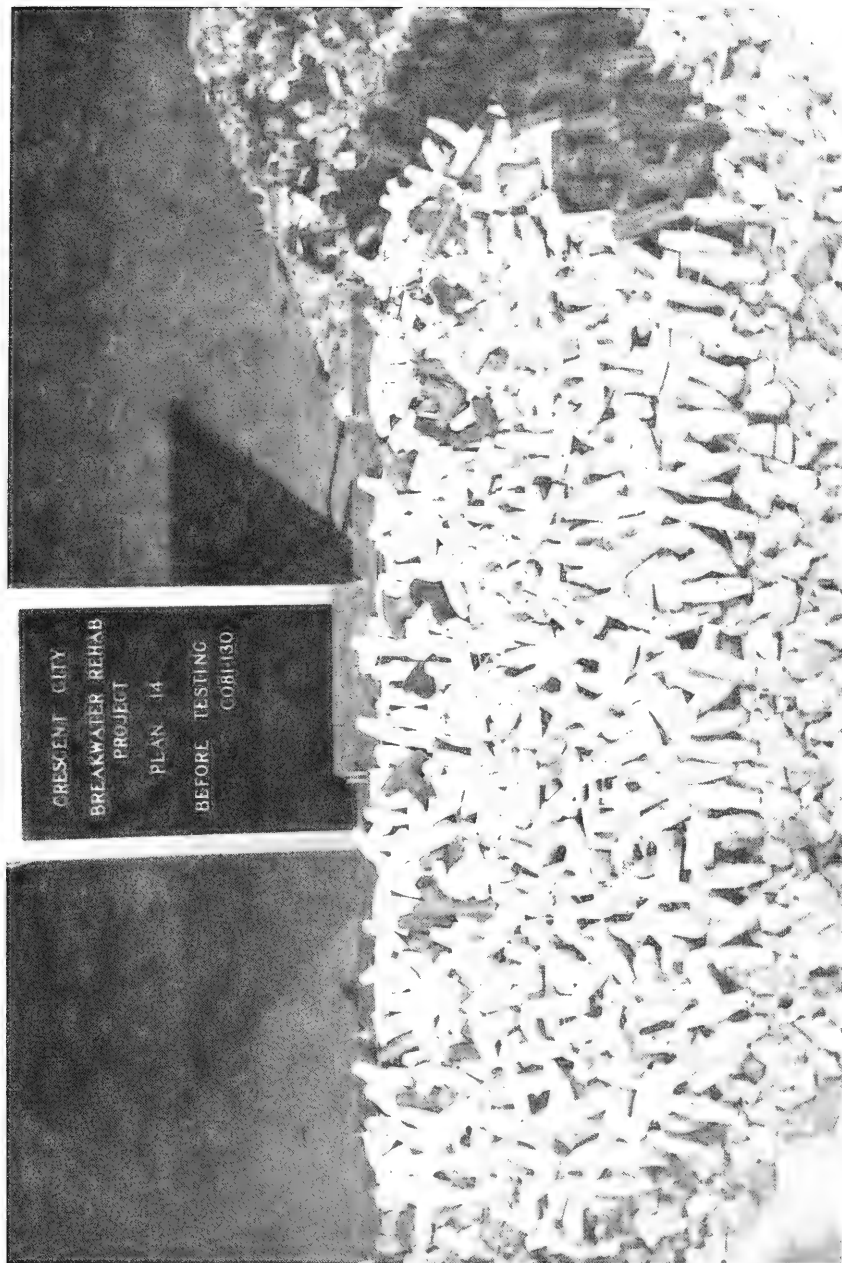


Photo 111. Sea-side view of Plan 14 before wave attack



Photo 112. Seaward oblique view of Plan 14 before wave attack



Photo 113. Seaward end view of Plan 14 before wave attack

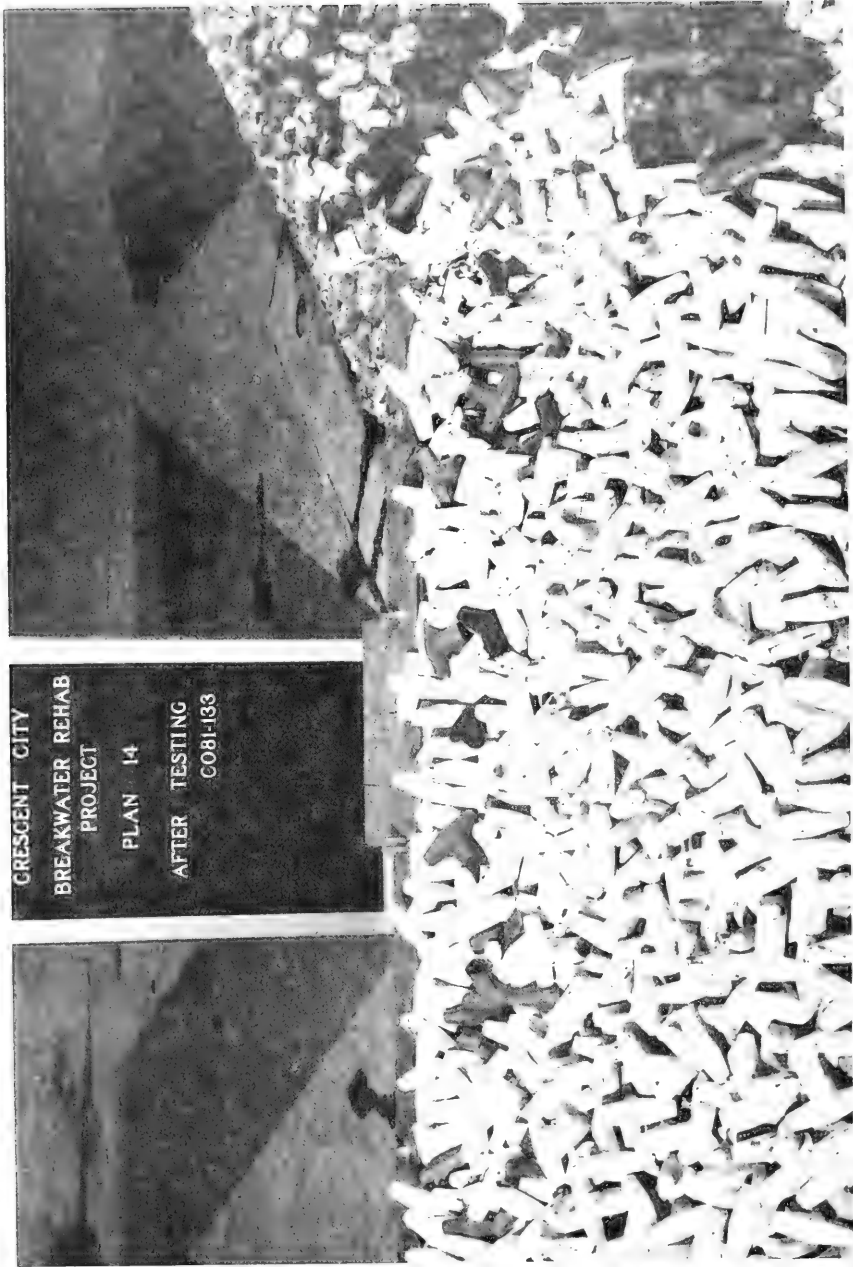


Photo 114. Sea-side view of Plan 14 after completion of abbreviated hydrograph



Photo 115. Seaward oblique view of Plan 14 after completion of abbreviated hydrograph

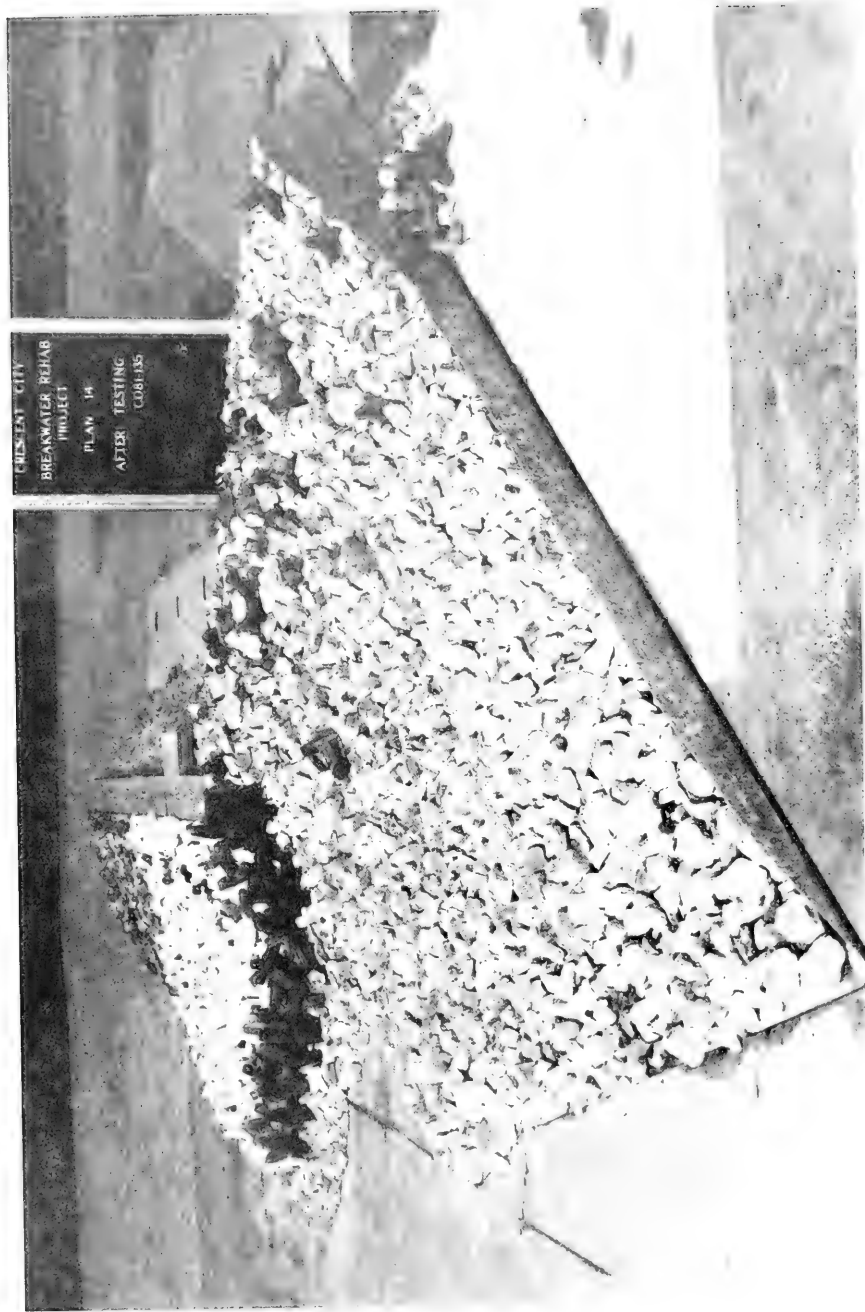


Photo 116. Seaward end view of Plan 14 after completion of abbreviated hydrograph

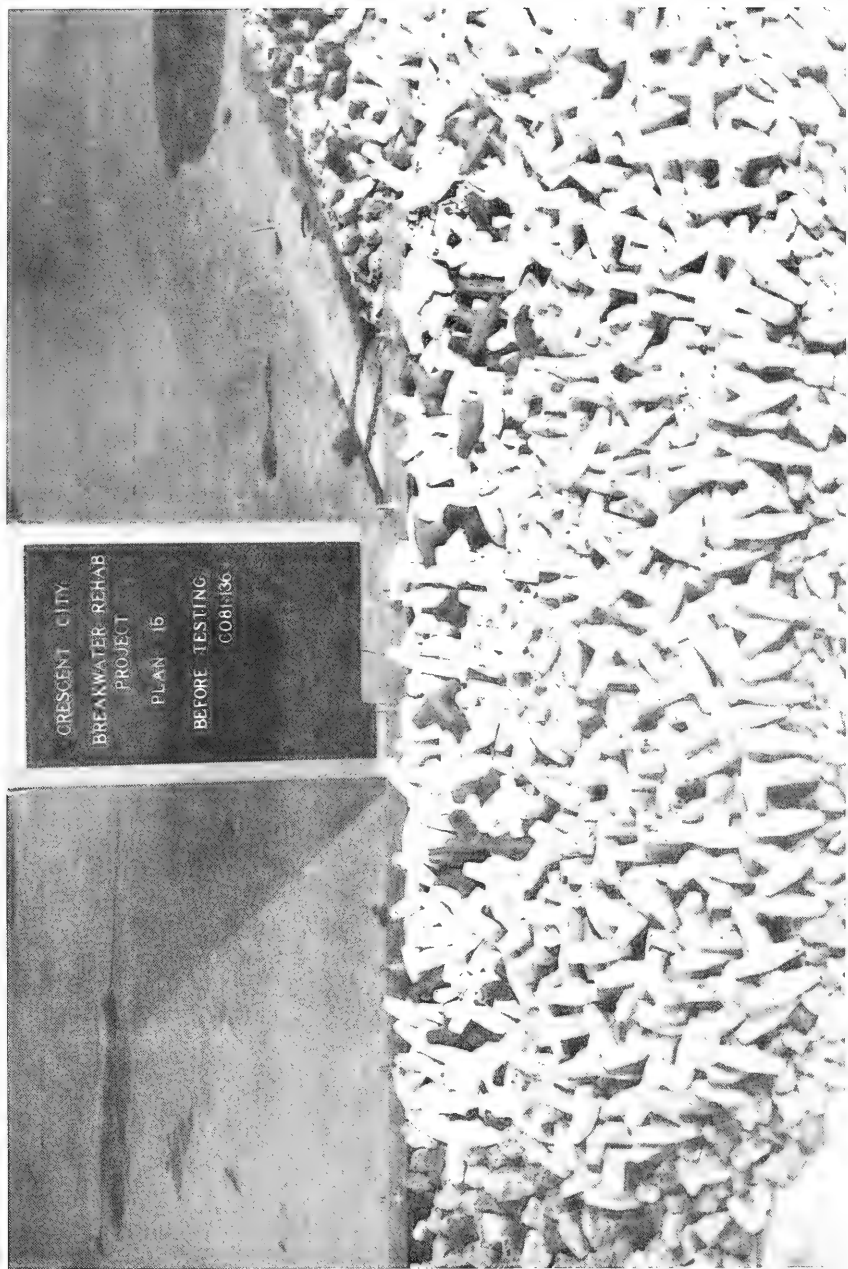


Photo 117. Sea-side view of Plan 15 before wave attack



Photo 118. Seaward oblique view of Plan 15 before wave attack



Photo 119. Seaward end view of Plan 15 before wave attack

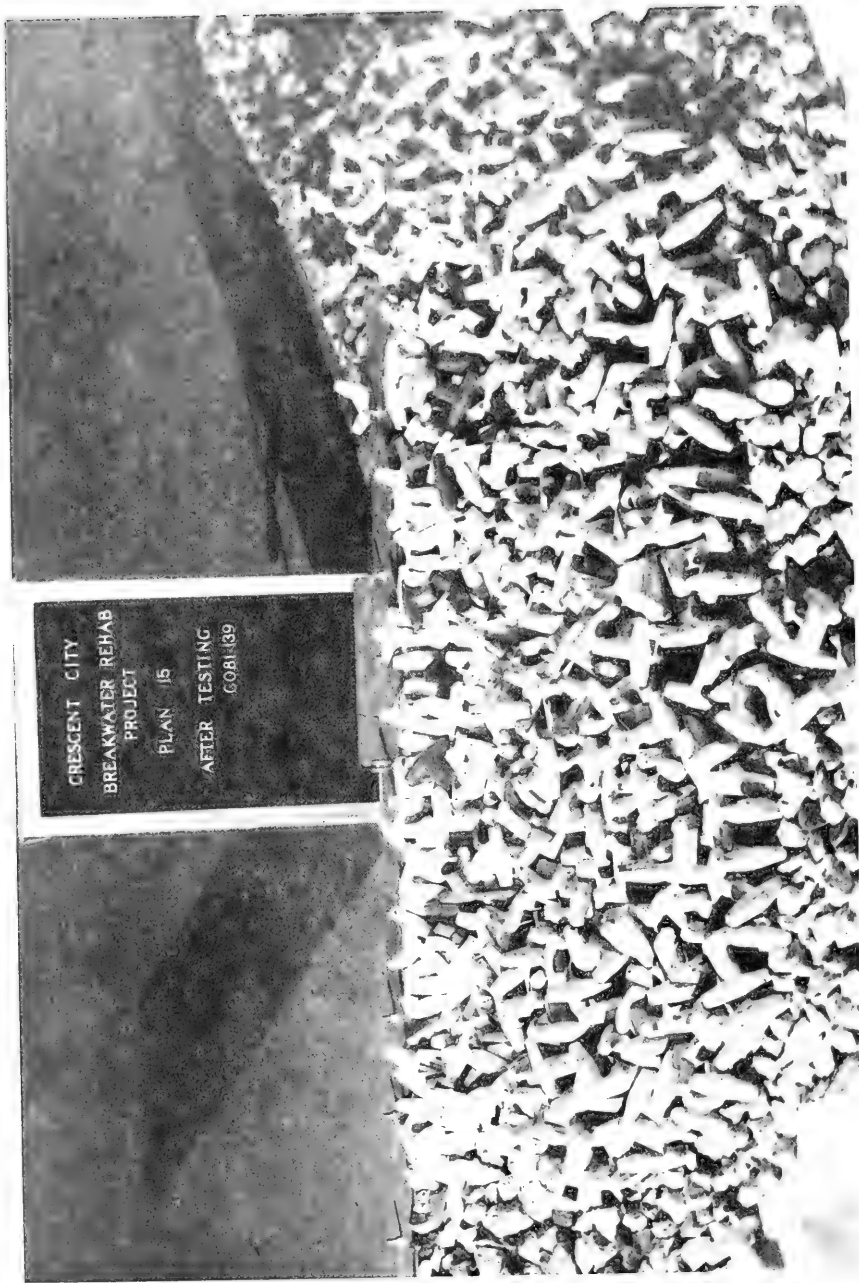


Photo 120. Sea-side view of Plan 15 after completion of abbreviated hydrograph



Photo 121. Seaward oblique view of Plan 15 after completion of abbreviated hydrograph



Photo 122. Seaward end view of Plan 15 after completion of abbreviated hydrograph

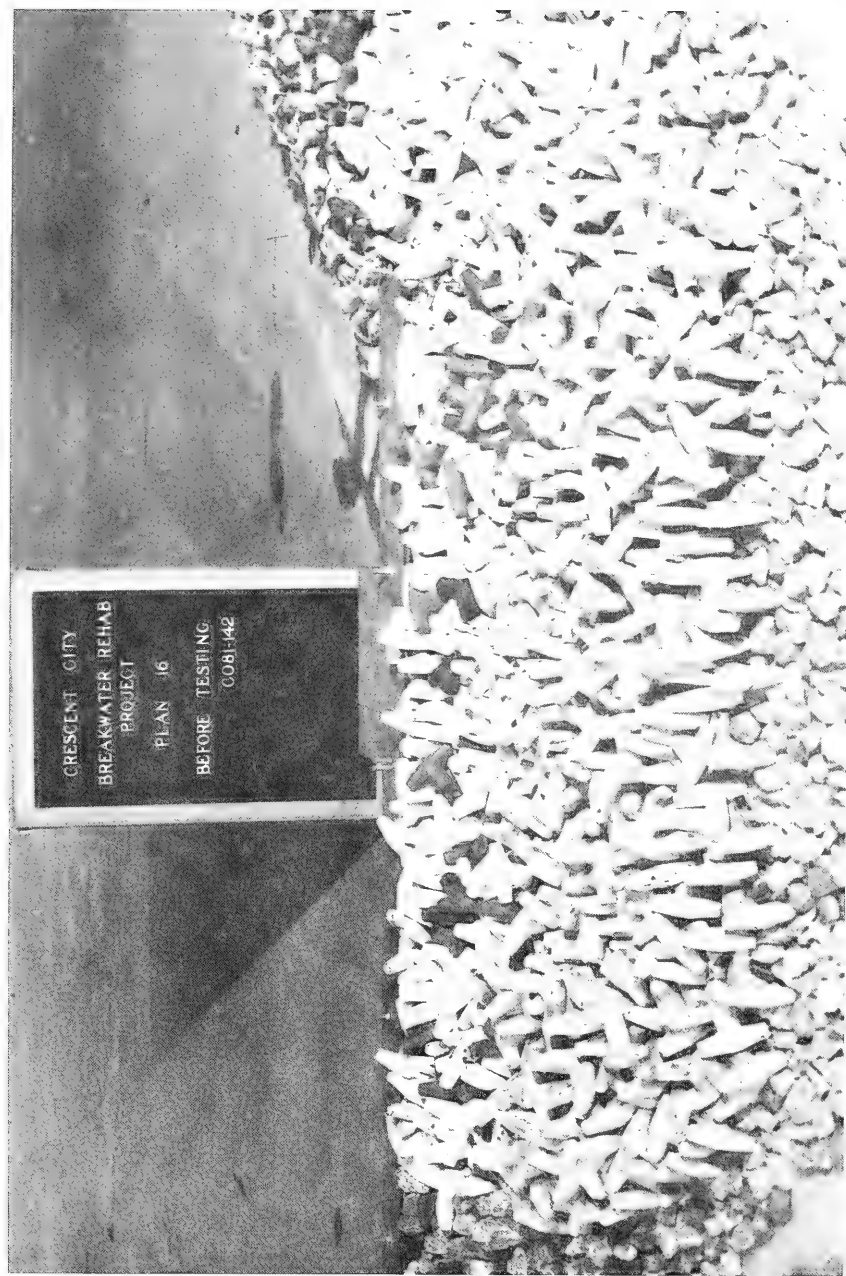


Photo 123. Sea-side view of Plan 16 before wave attack



Photo 124. Seaward oblique view of Plan 16 before wave attack



Photo 125. Seaward end view of Plan 16 before wave attack

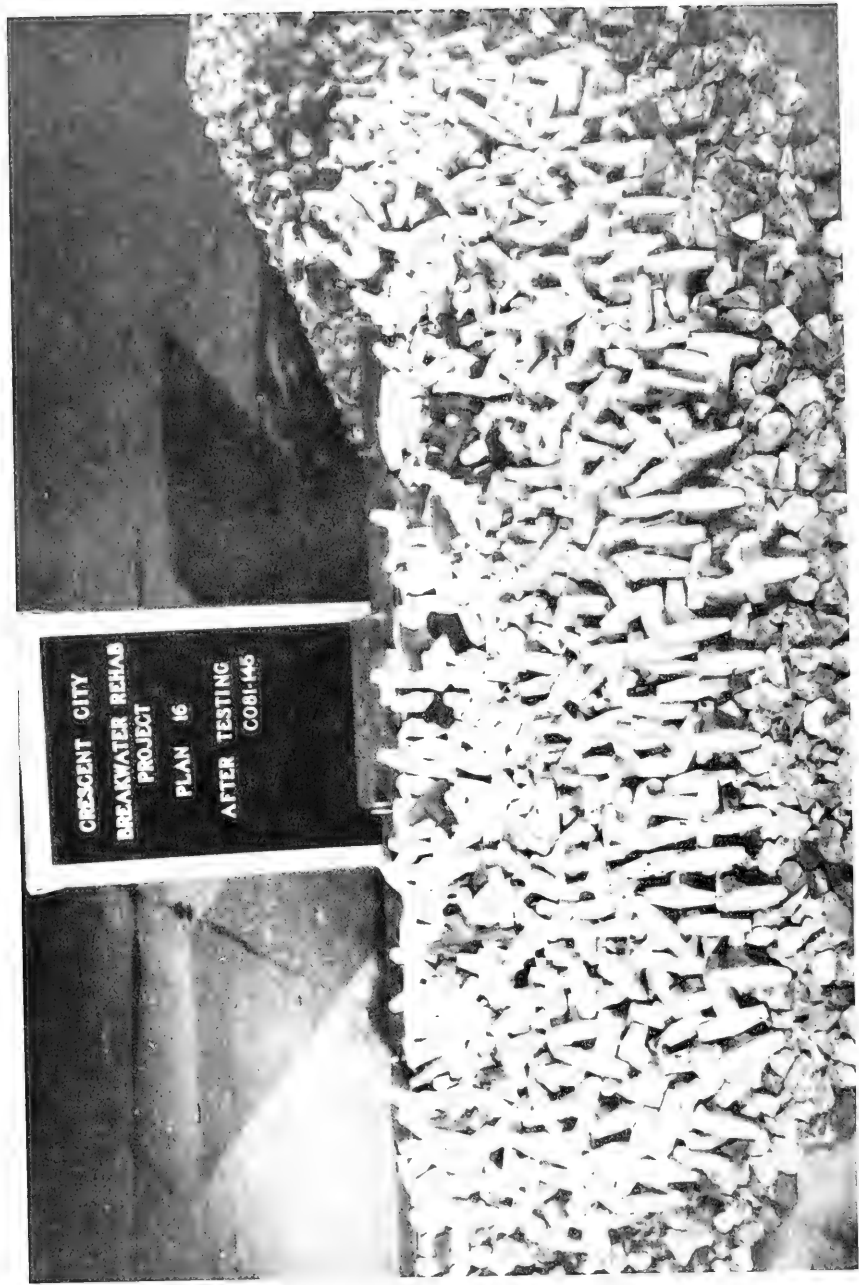


Photo 126. Sea-side view of Plan 16 after completion of abbreviated hydrograph

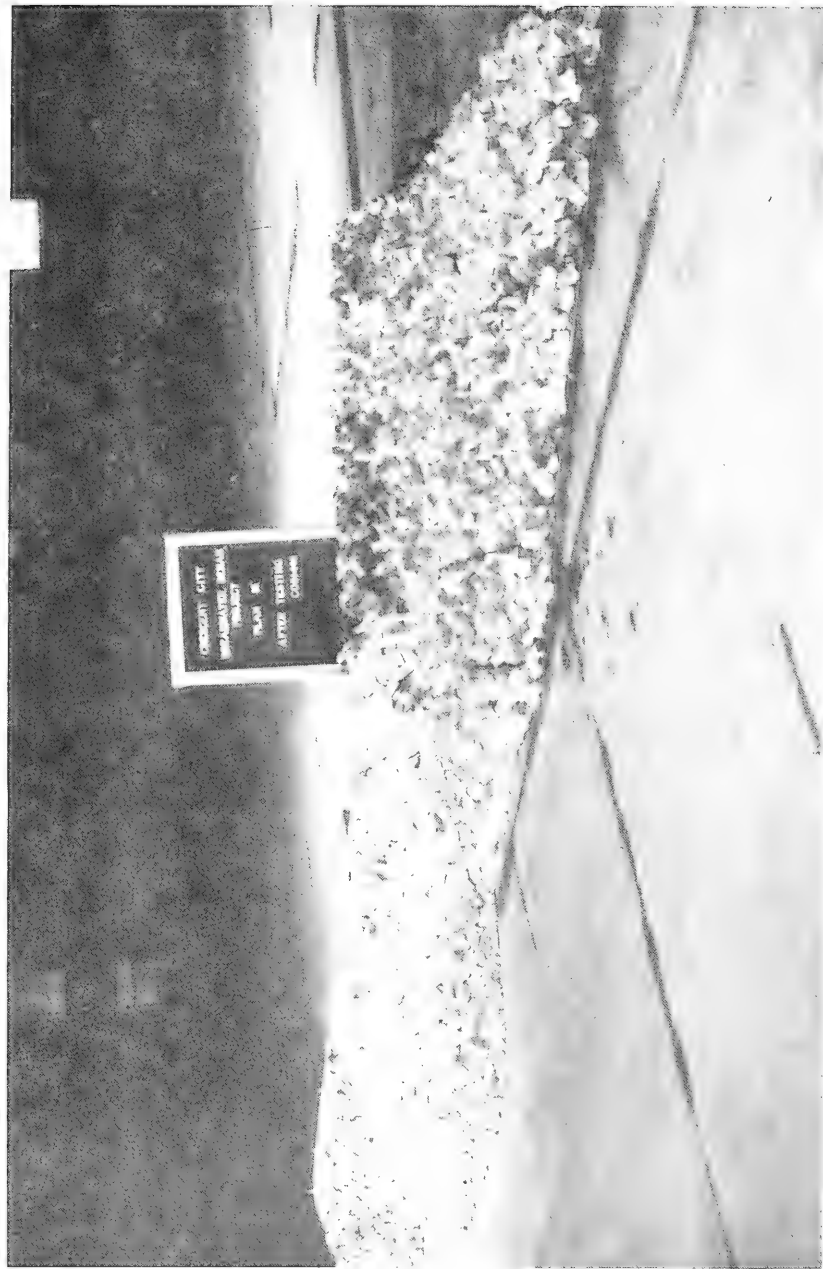


Photo 127. Seaward oblique view of Plan 16 after completion of abbreviated hydrograph



Photo 128. Seaward end view of Plan 16 after completion of abbreviated hydrograph

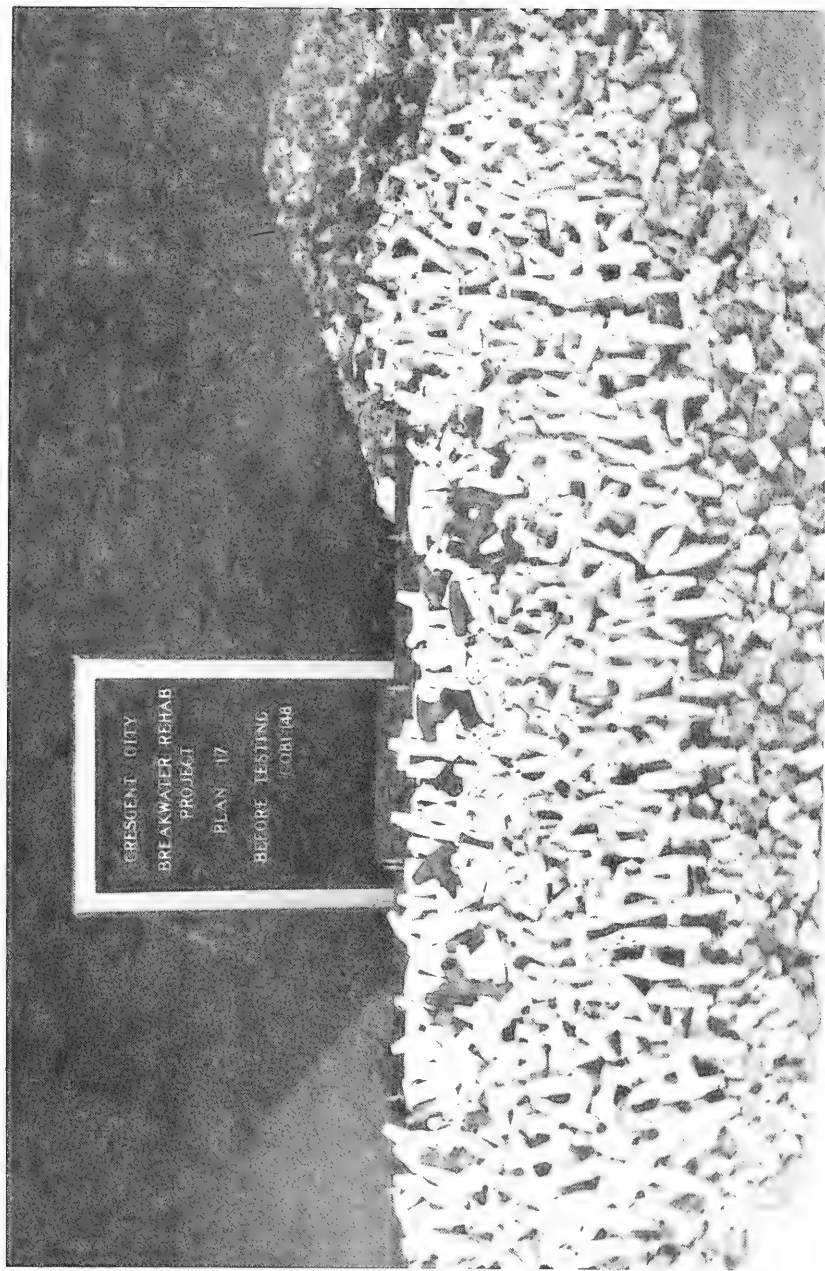


Photo 129. Sea-side view of Plan 17 before wave attack

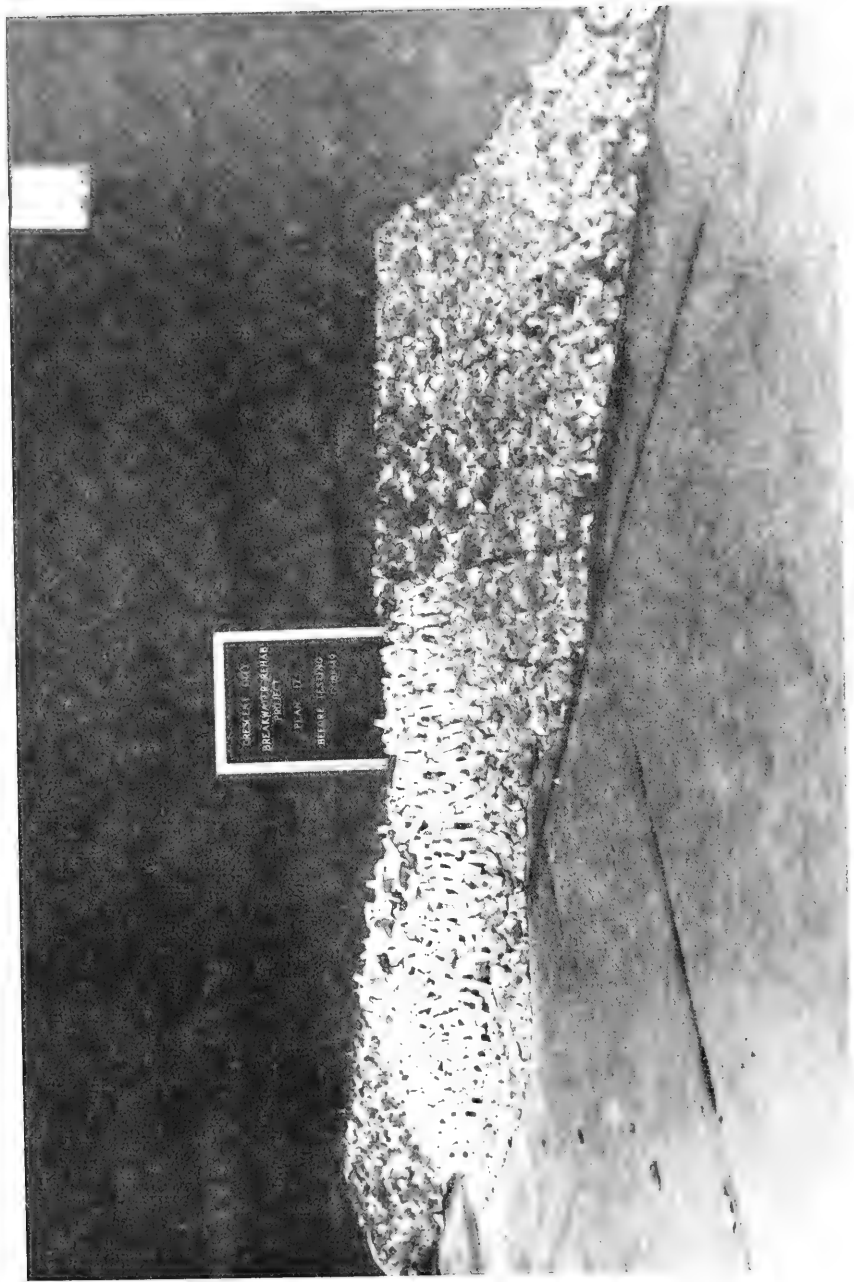


Photo 130. Seaward oblique view of Plan 17 before wave attack



Photo 131. Seaward end view of Plan 17 before wave attack

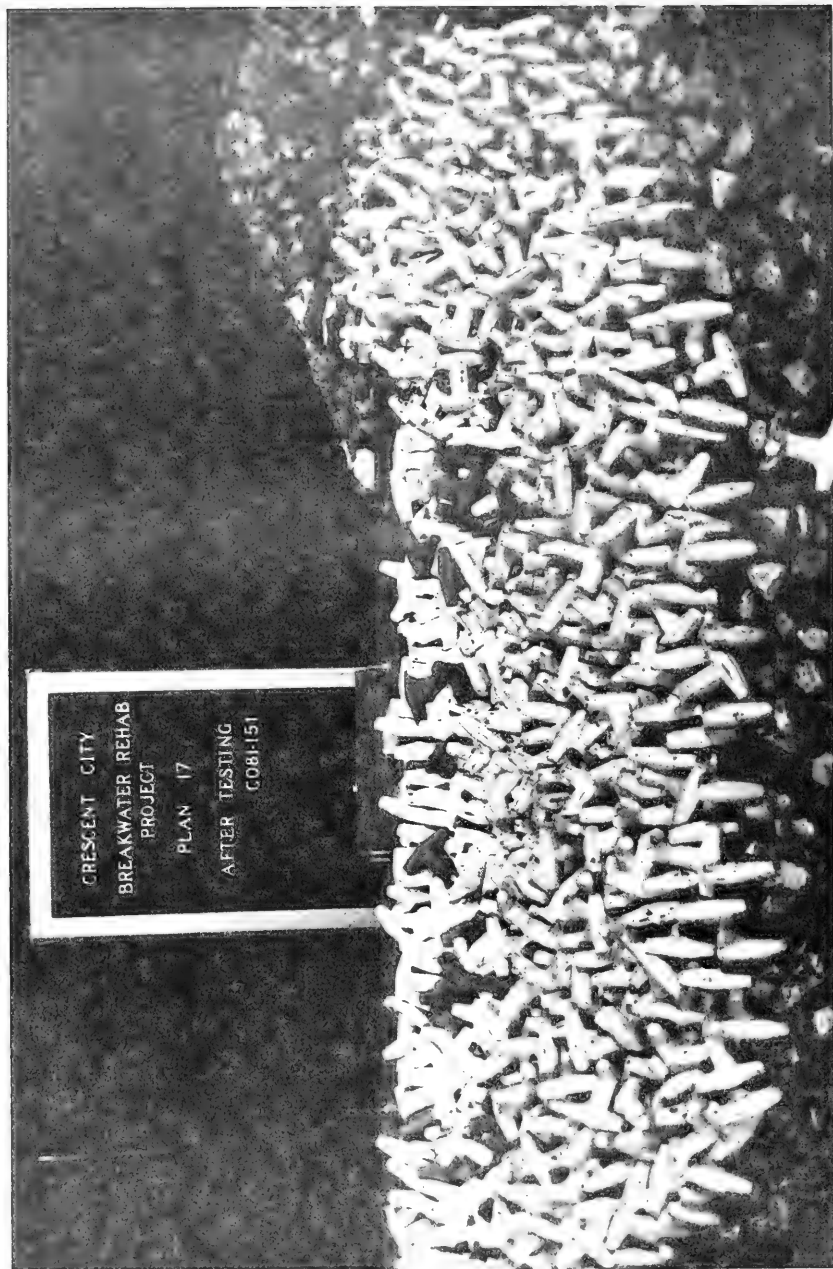


Photo 132. Sea-side view of Plan 17 after completion of abbreviated hydrograph



Photo 133. Seaward oblique view of Plan 17 after completion of abbreviated hydrograph

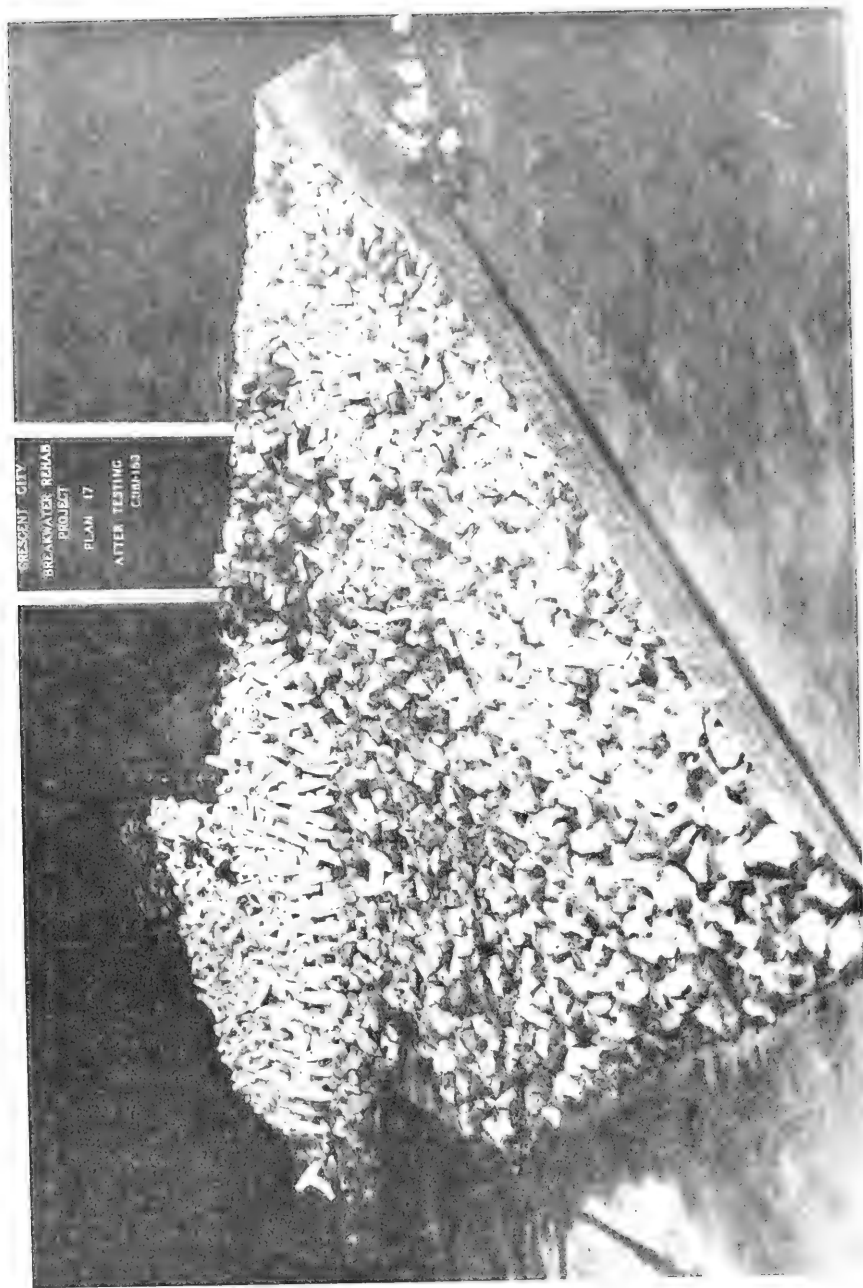


Photo 134. Seaward end view of Plan 17 after completion of abbreviated hydrograph

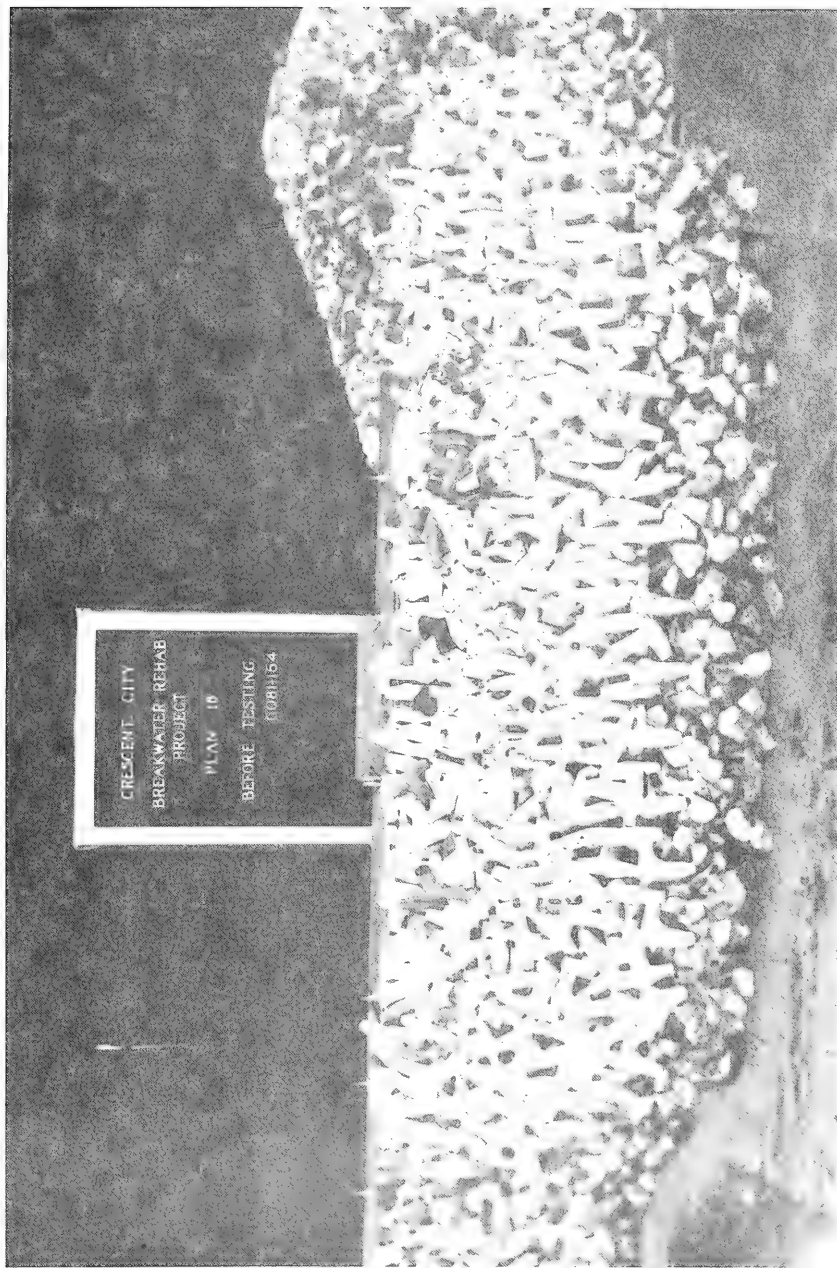


Photo 135. Sea-side view of Plan 18 before wave attack

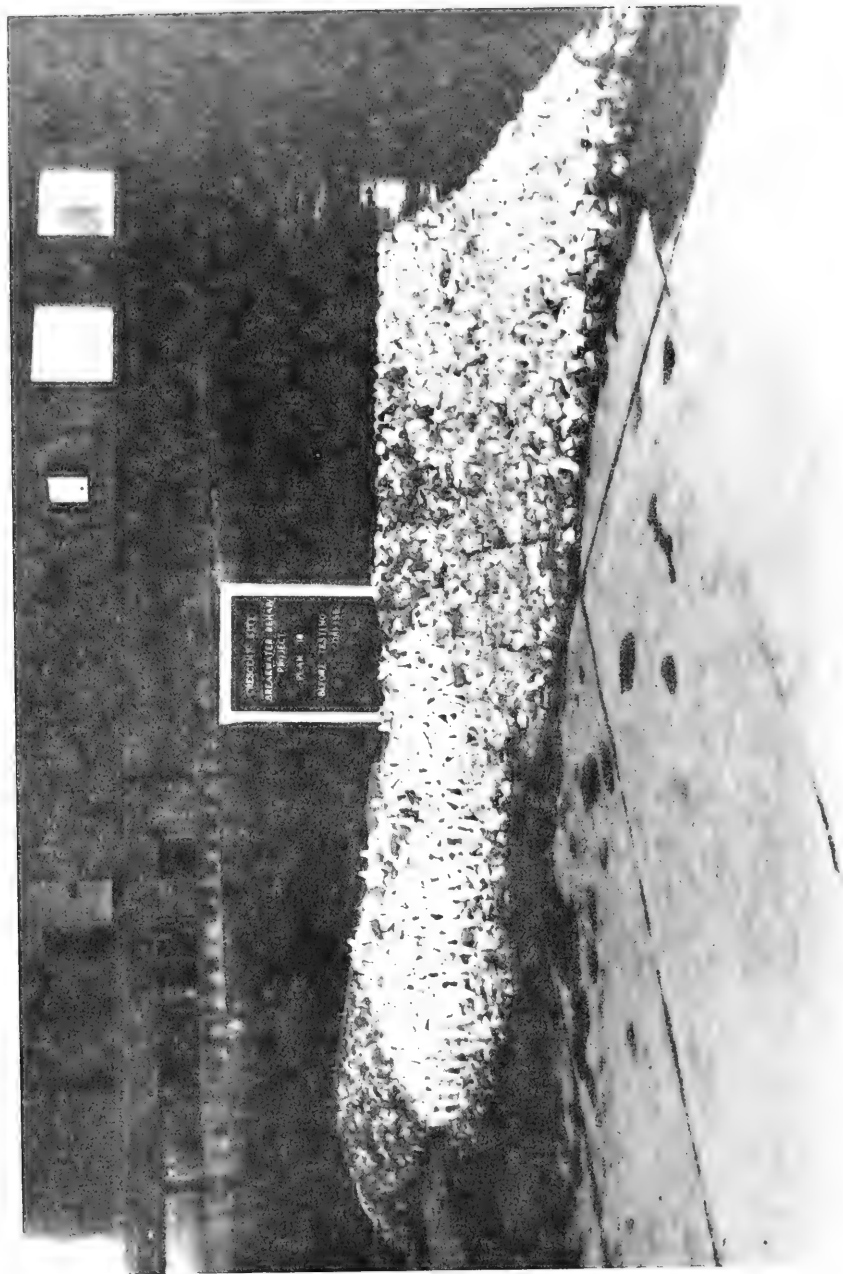


Photo 136. Seaward oblique view of Plan 18 before wave attack

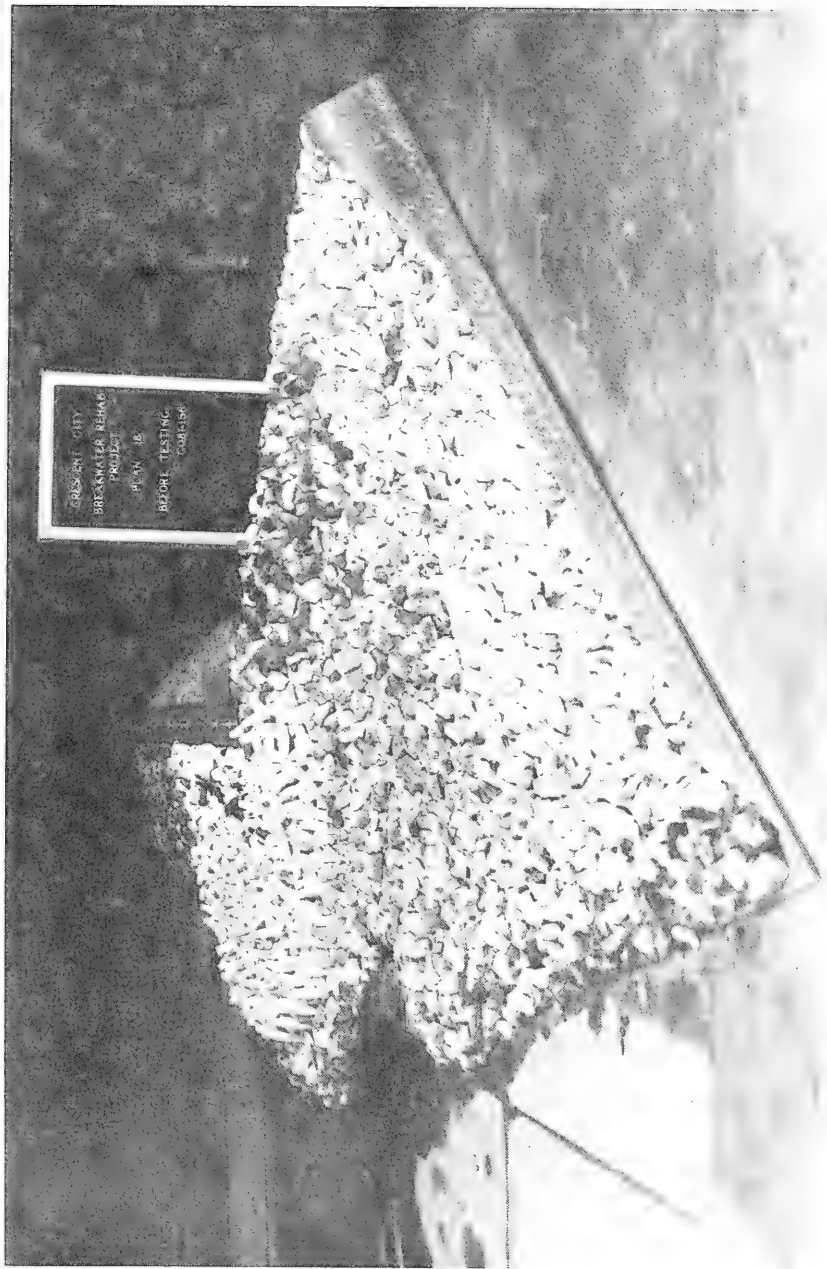


Photo 137. Seaward end view of Plan 18 before wave attack

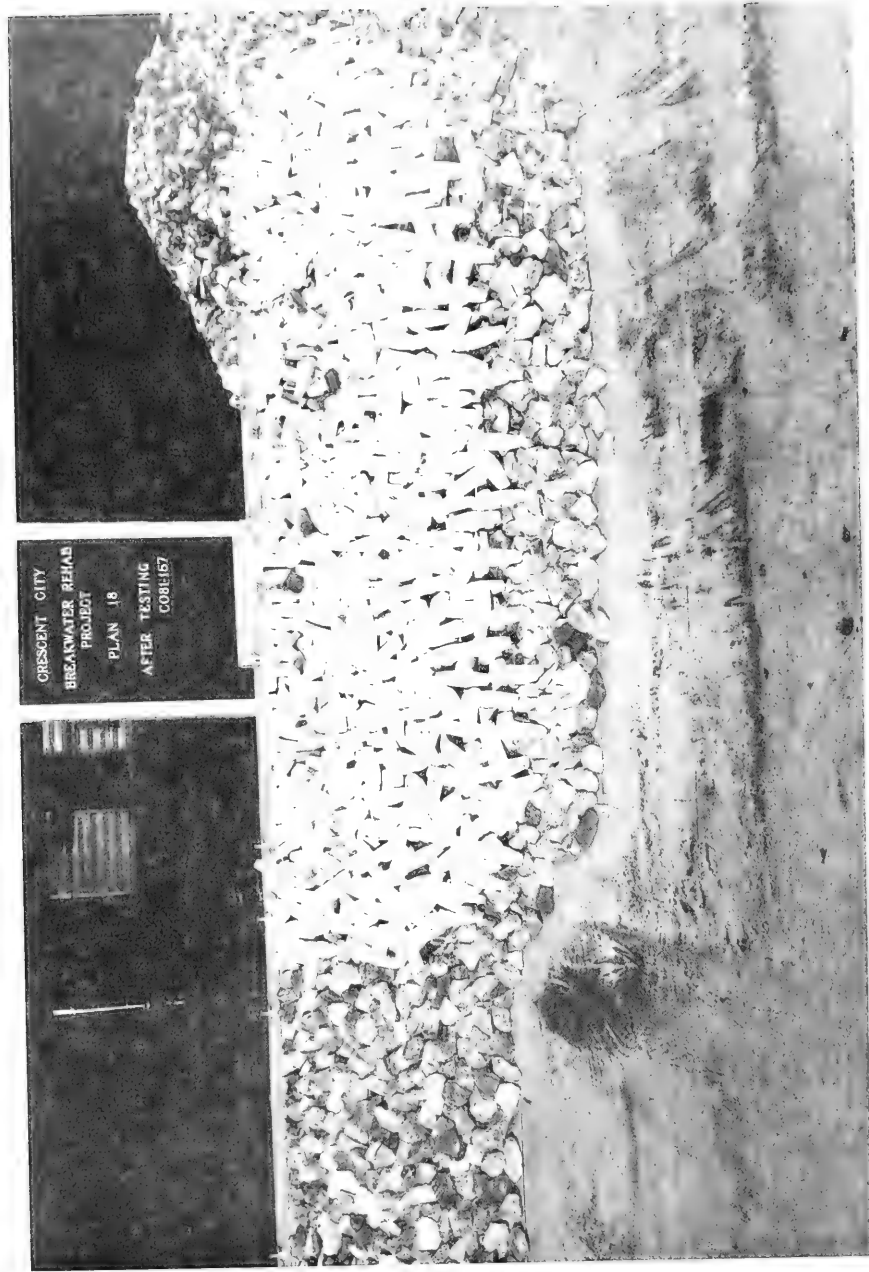


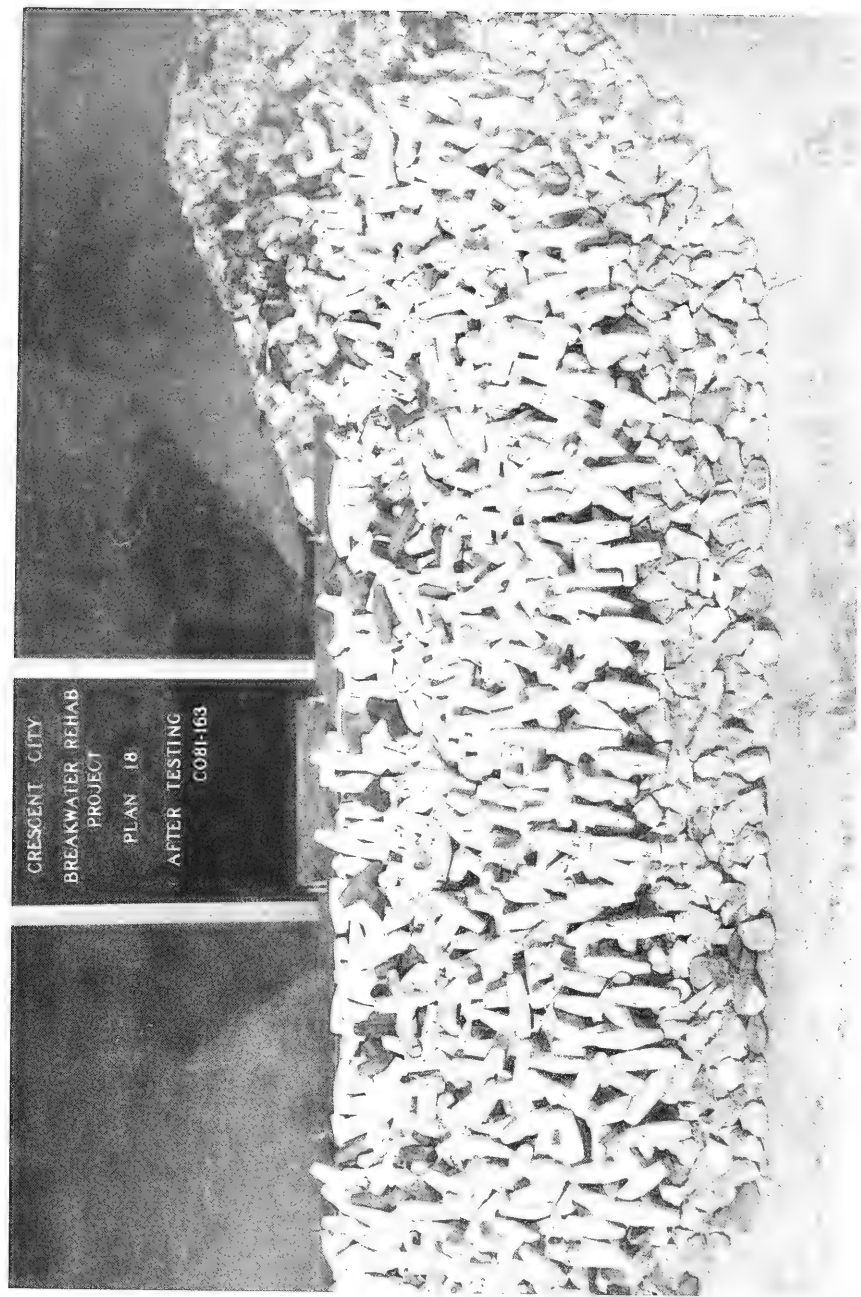
Photo 138. Sea-side view of Plan 18 after completion of abbreviated hydrograph



Photo 139. Seaward oblique view of Plan 18 after completion of abbreviated hydrograph



Photo 140. Seaward end view of Plan 18 after completion of abbreviated hydrograph



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Photo 141. Sea-side view of Plan 18 repeat after completion of abbreviated hydrograph

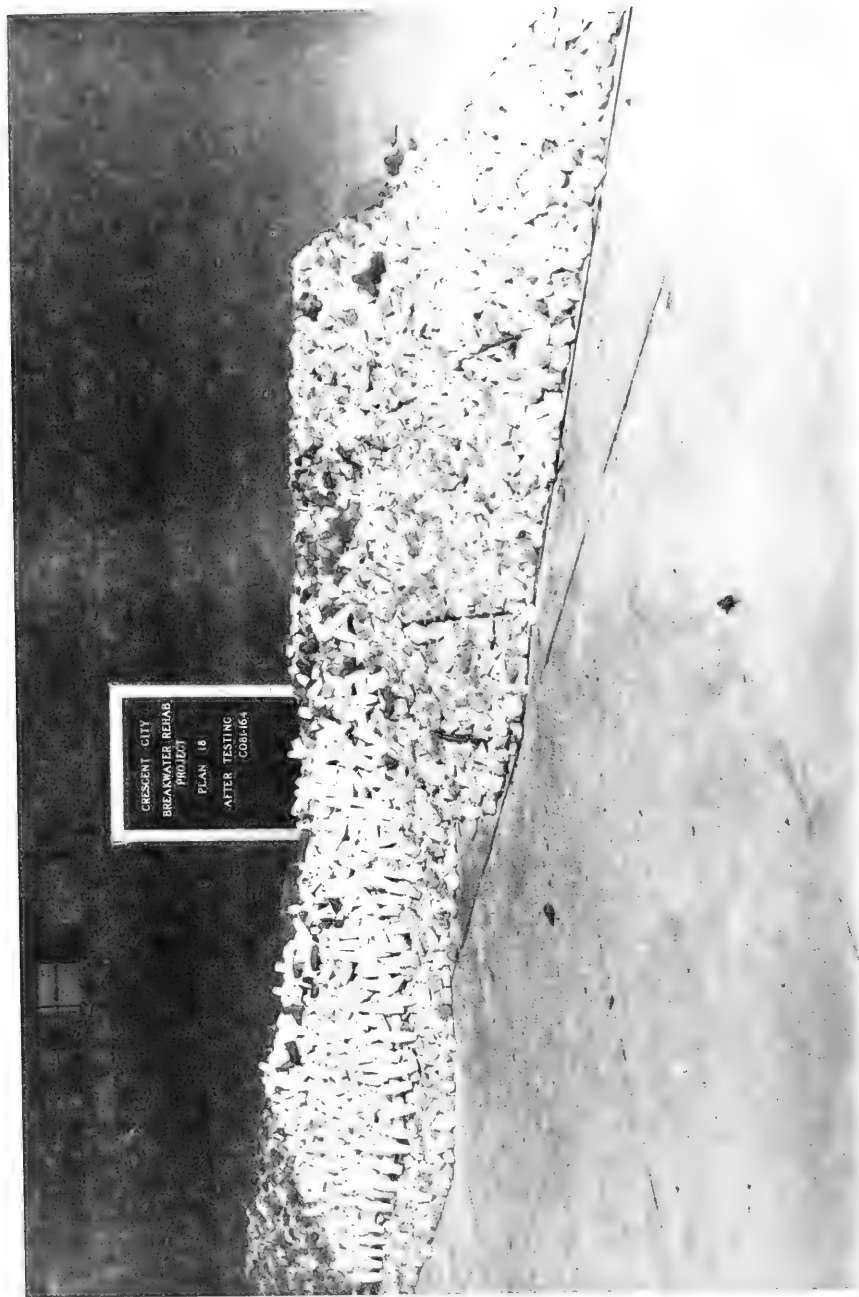


Photo 142. Seaward oblique view of Plan 18 repeat after completion of abbreviated hydrograph



Photo 143. Seaward end view of Plan 18 repeat after completion of abbreviated hydrograph

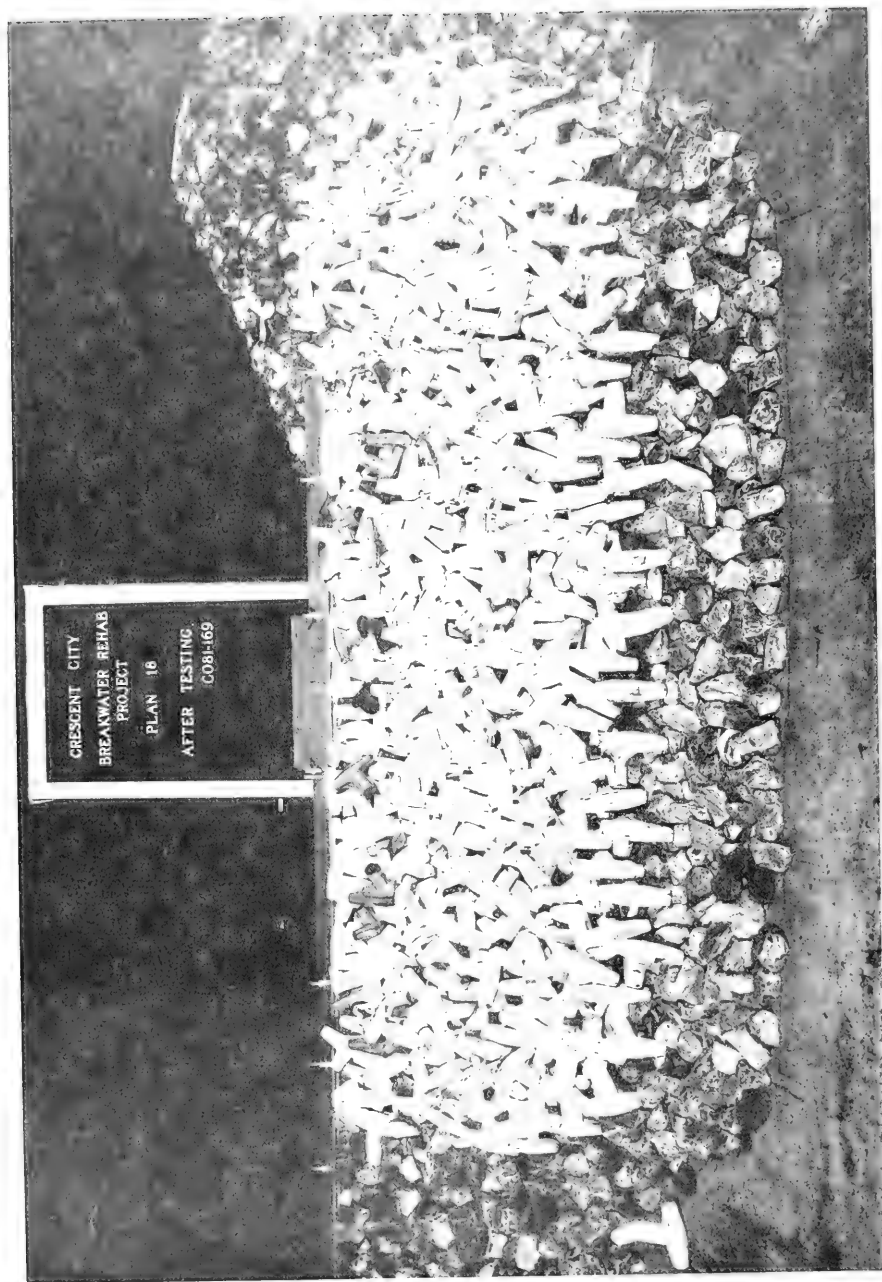


Photo 144. Sea-side view of Plan 18 after completion of Hydrograph A

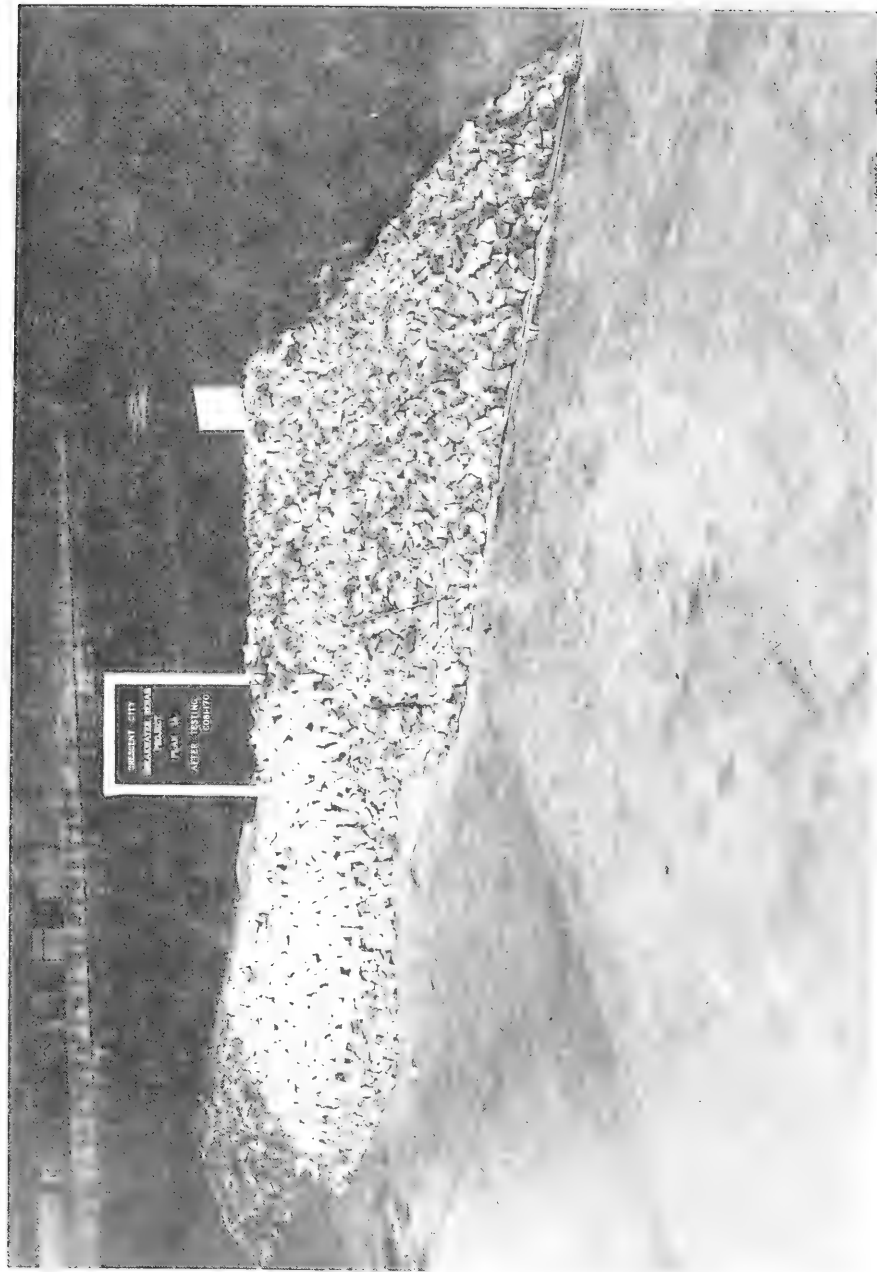


Photo 145. Seaward oblique view of Plan 18 after completion of Hydrograph A



Photo 146. Seaward end view of Plan 18 after completion of Hydrograph A

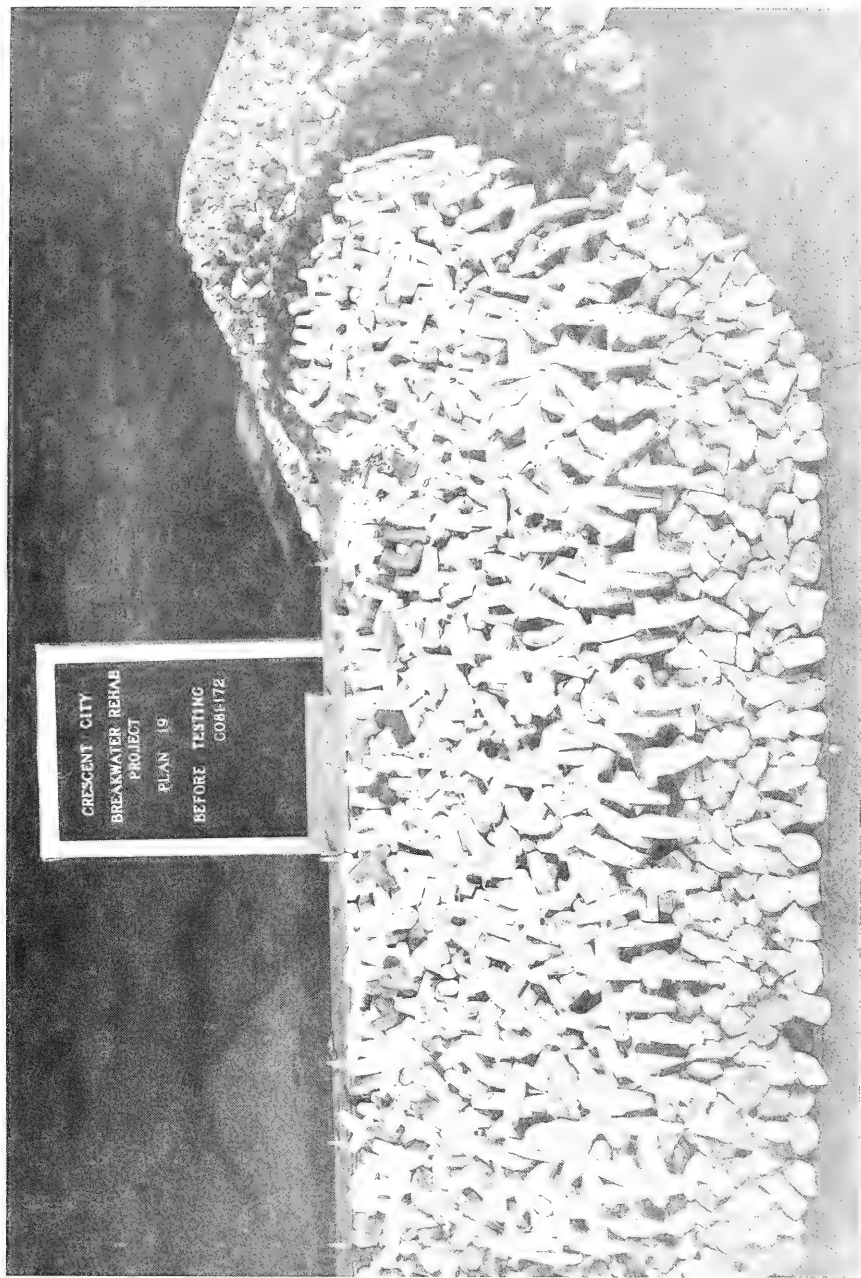


Photo 147. Sea-side view of Plan 19 before wave attack

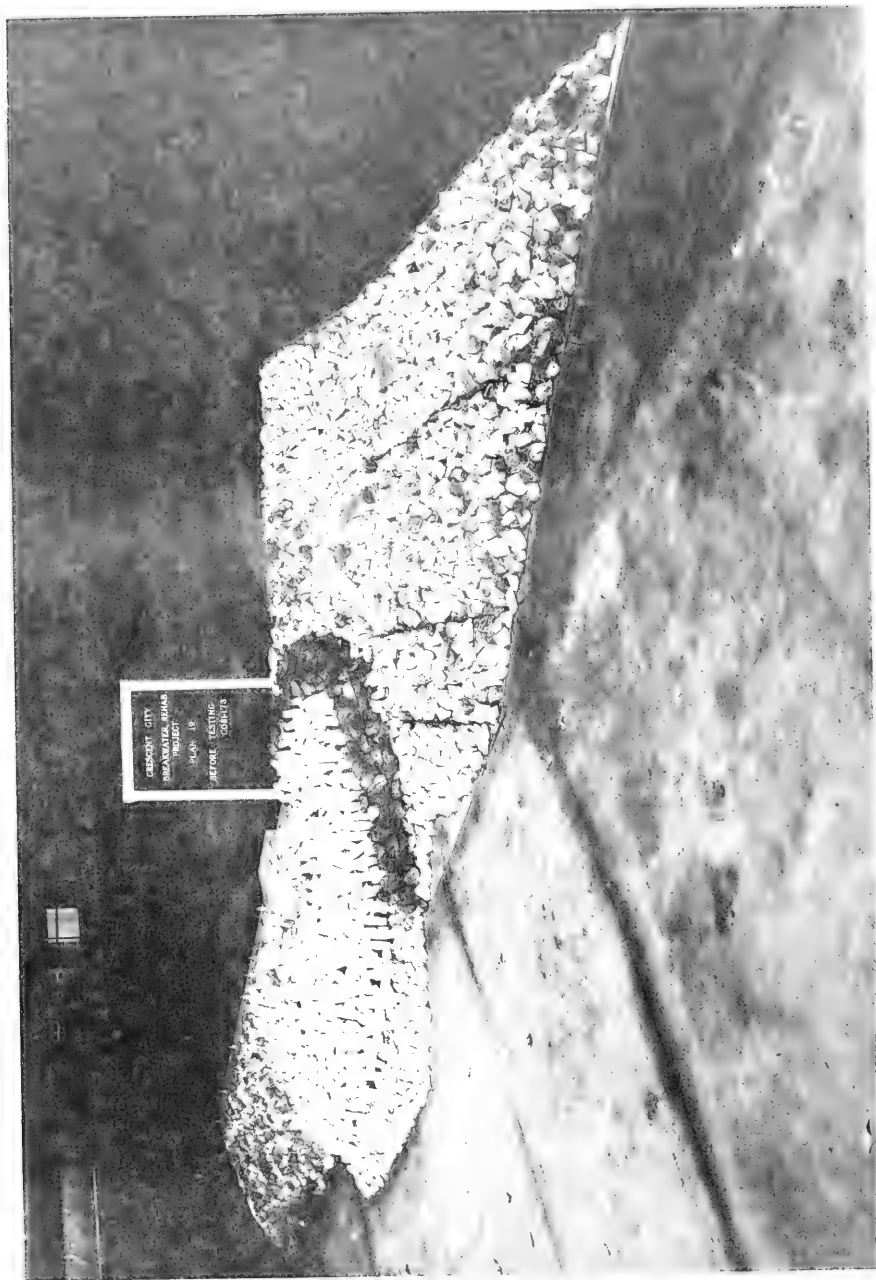


Photo 148. Seaward oblique view of Plan 19 before wave attack

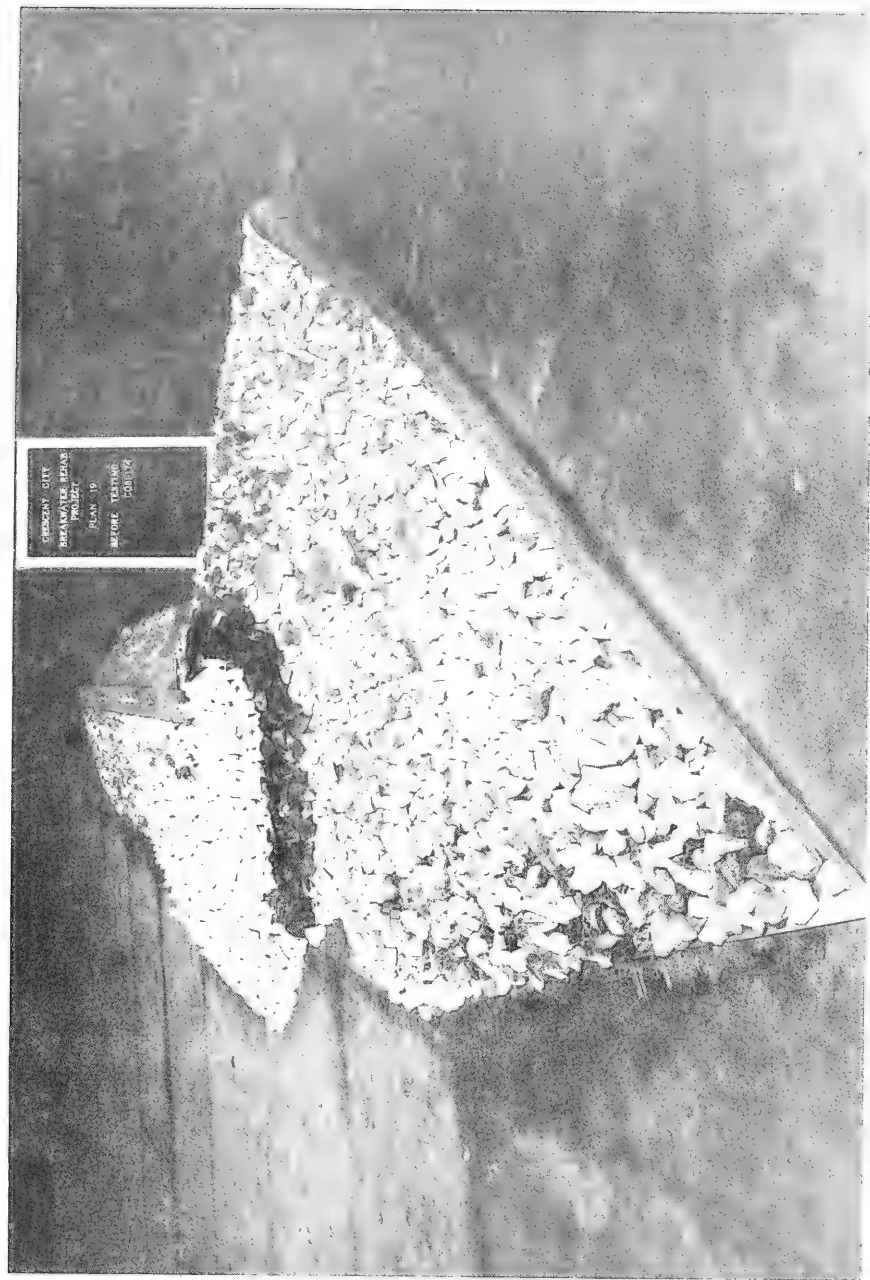


Photo 149. Seaward end view of Plan 19 before wave attack

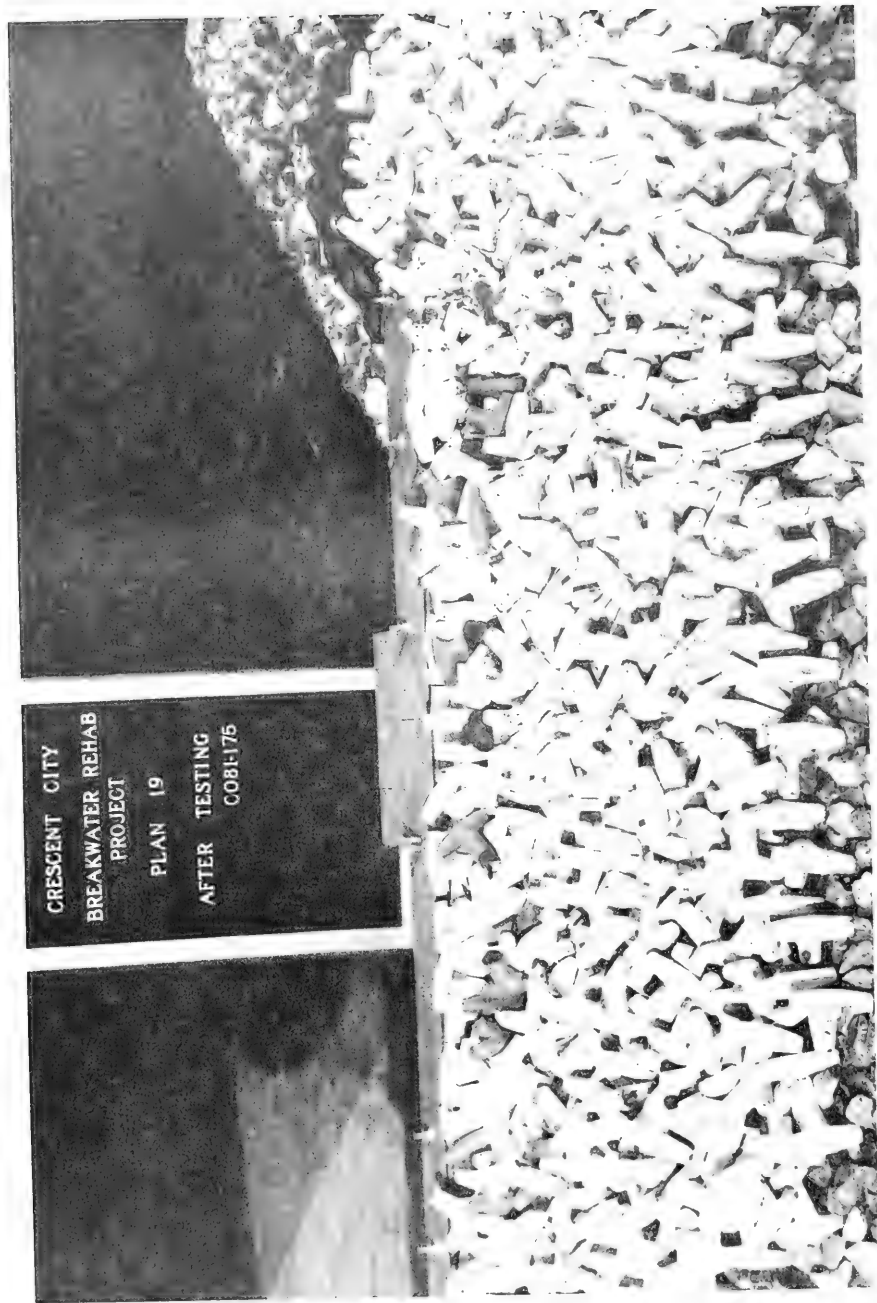


Photo 150. Sea-side view of Plan 19 after completion of abbreviated hydrograph



Photo 151. Seaward oblique view of Plan 19 after completion of abbreviated hydrograph



Photo 152. Seaward end view of Plan 19 after completion of abbreviated hydrograph

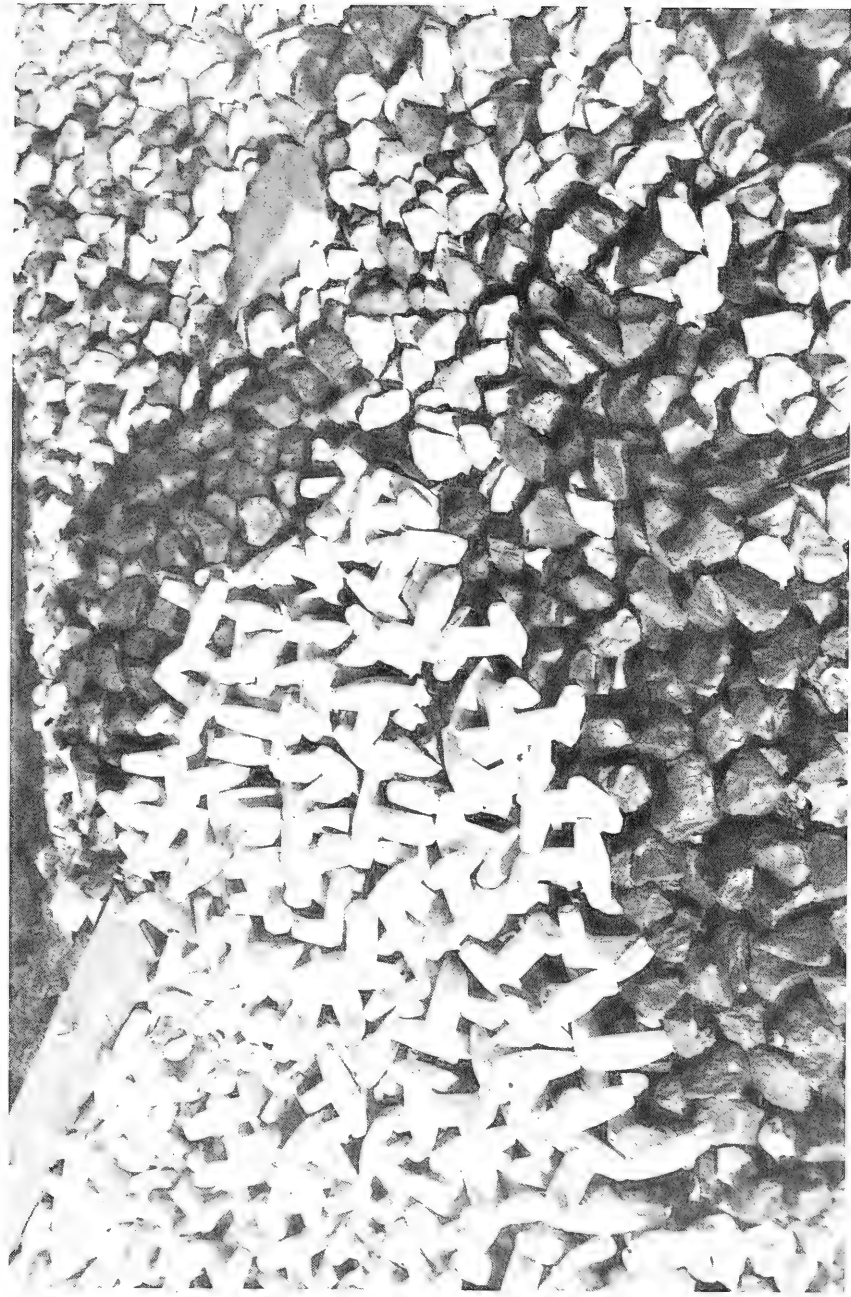


Photo 153. Closeup view of seaward transition for Plan 19 after completion of abbreviated hydrograph

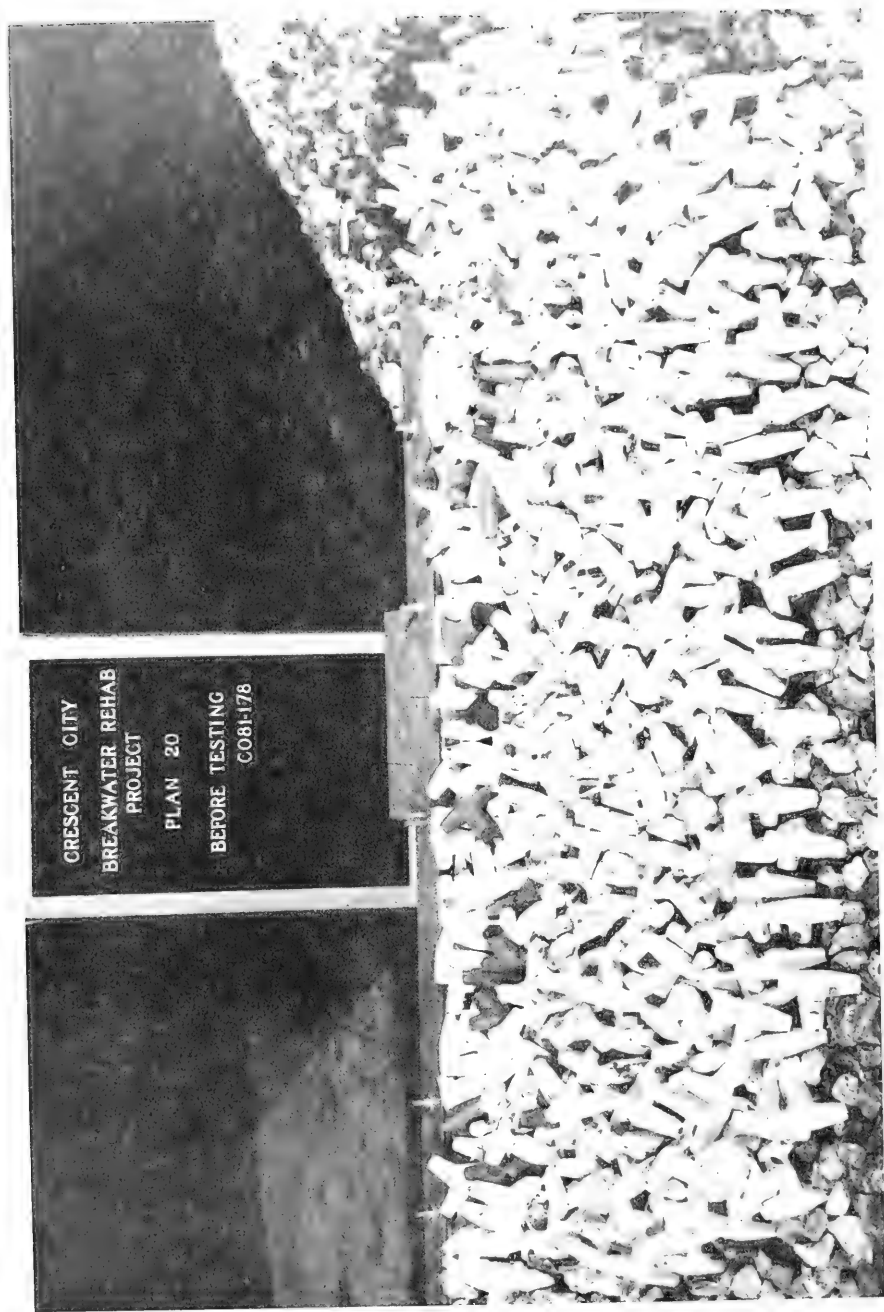


Photo 154. Sea-side view of Plan 20 before wave attack



Photo 155. Seaward oblique view of Plan 20 before wave attack

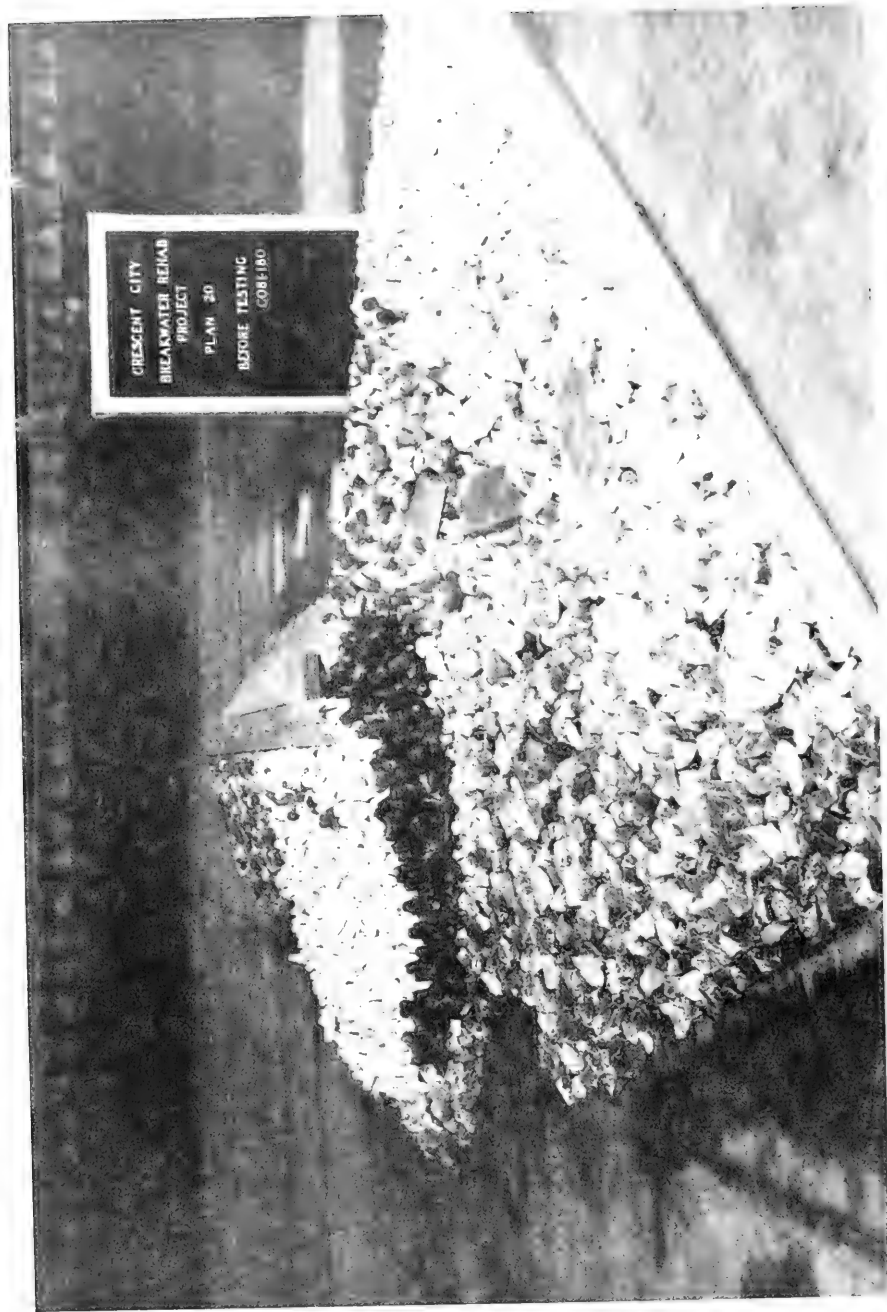


Photo 156. Seaward end view of Plan 20 before wave attack

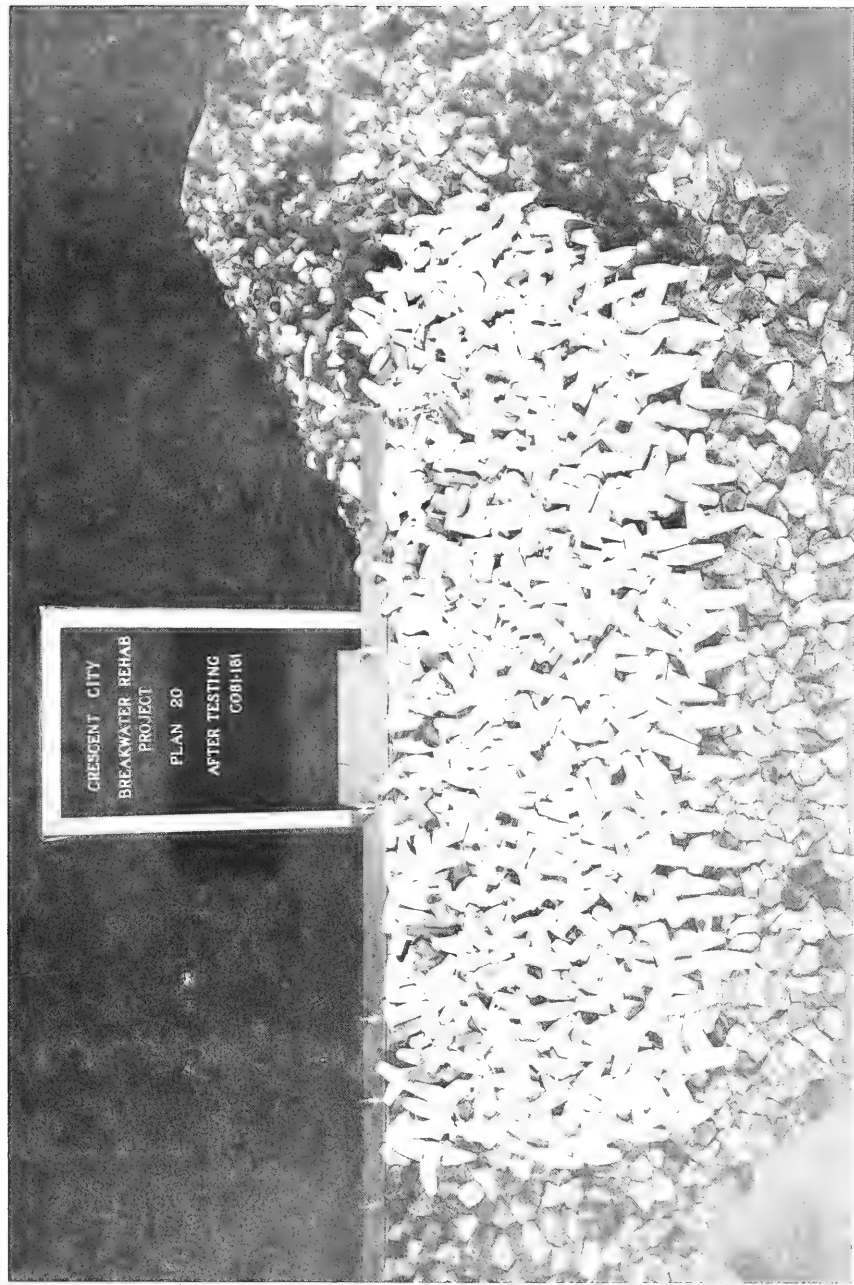


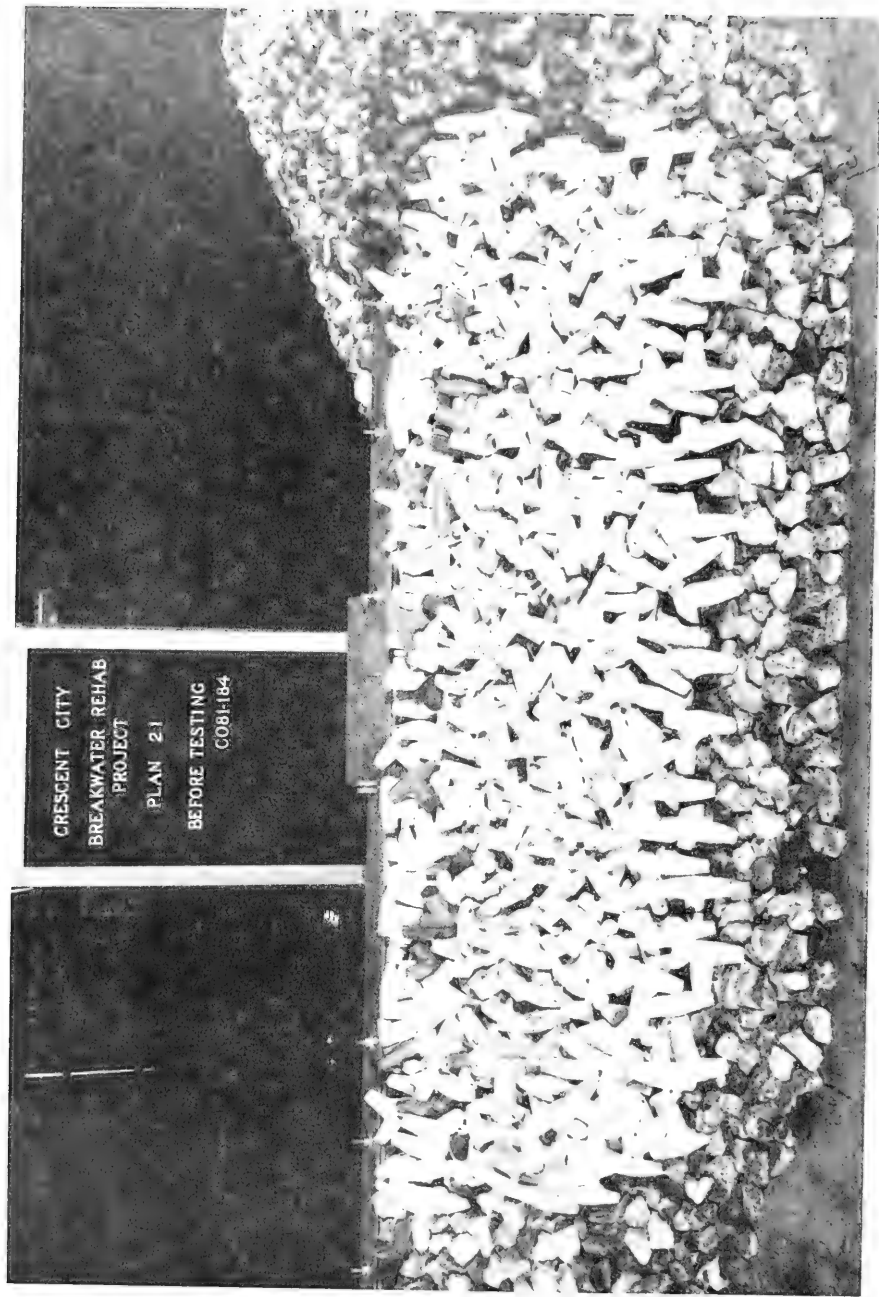
Photo 157. Sea-side view of Plan 20 after completion of abbreviated hydrograph



Photo 158. Seaward oblique view of Plan 20 after completion of abbreviated hydrograph



Photo 159. Seaward end view of Plan 20 after completion of abbreviated hydrograph



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Photo 160. Sea-side view of Plan 21 before wave attack

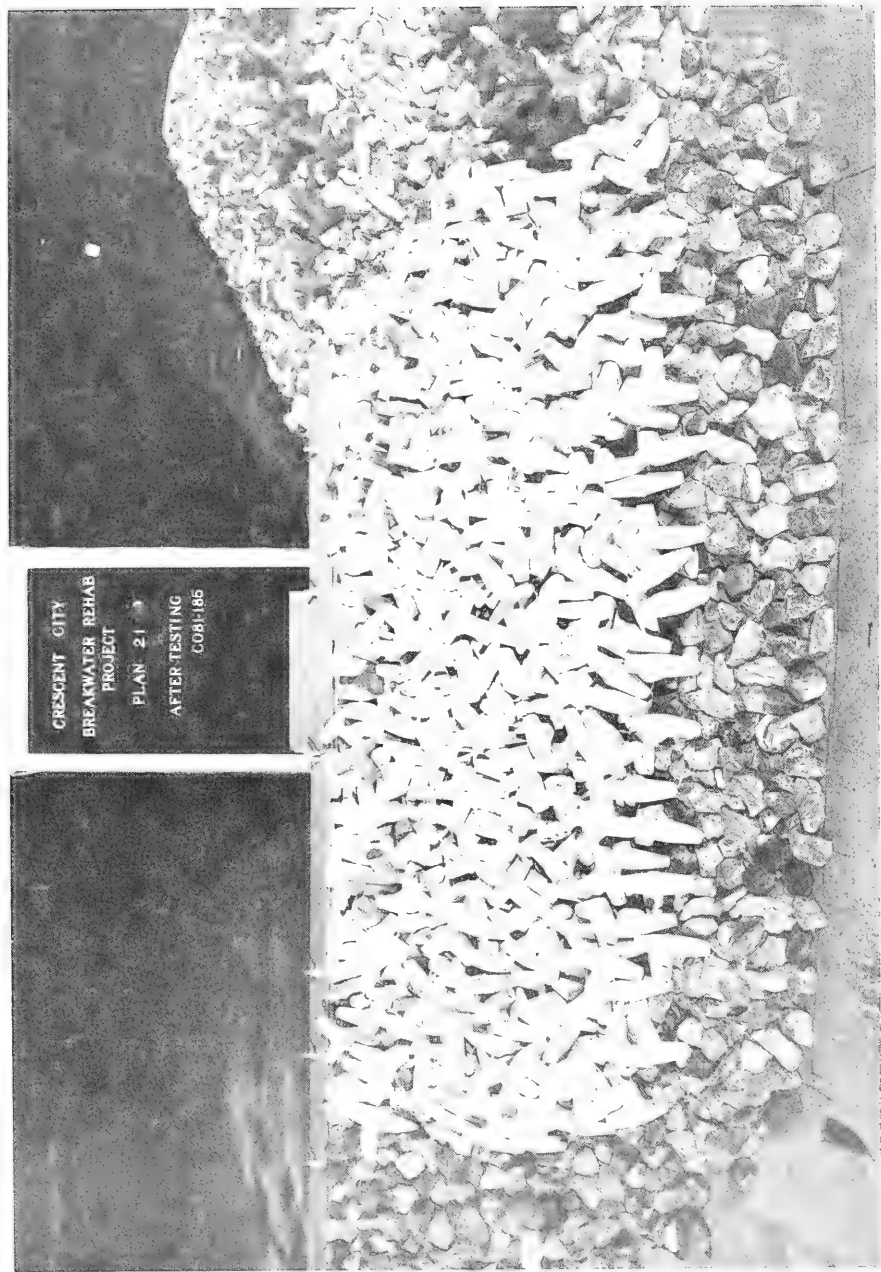


Photo 161. Seaward oblique view of Plan 21 before wave attack



Photo 162. Seaward end view of Plan 21 before wave attack



Photo 163. Sea-side view of Plan 21 after completion of abbreviated hydrograph



Photo 164. Seaward oblique view of Plan 21 after completion of abbreviated hydrograph



Photo 165. Seaward end view of Plan 21 after completion of abbreviated hydrograph

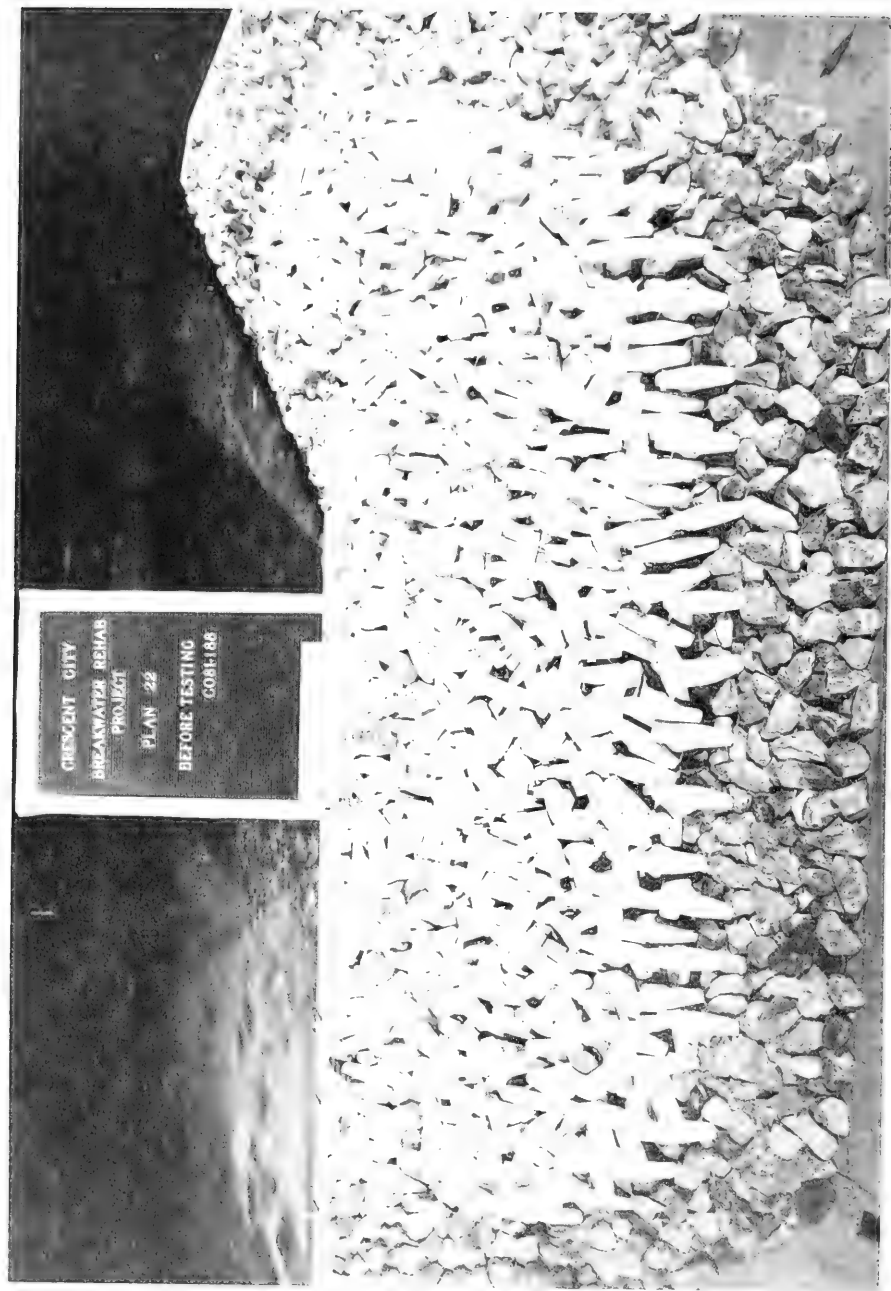
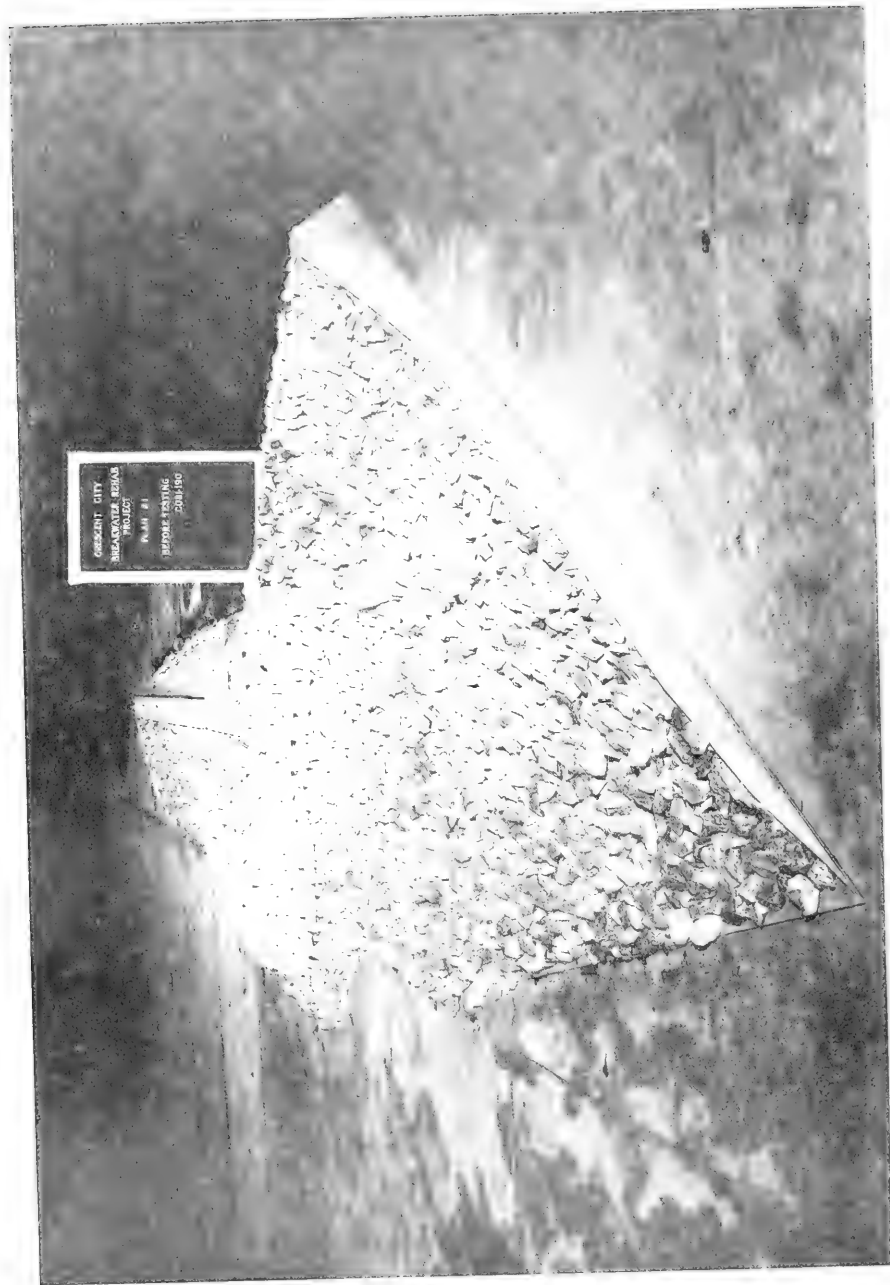


Photo 166. Sea-side view of Plan 22 before wave attack



Photo 167. Seaward oblique view of Plan 22 before wave attack



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10000
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BEDDING TESTING
200-190

Photo 168. Seaward end view of Plan 22 before wave attack

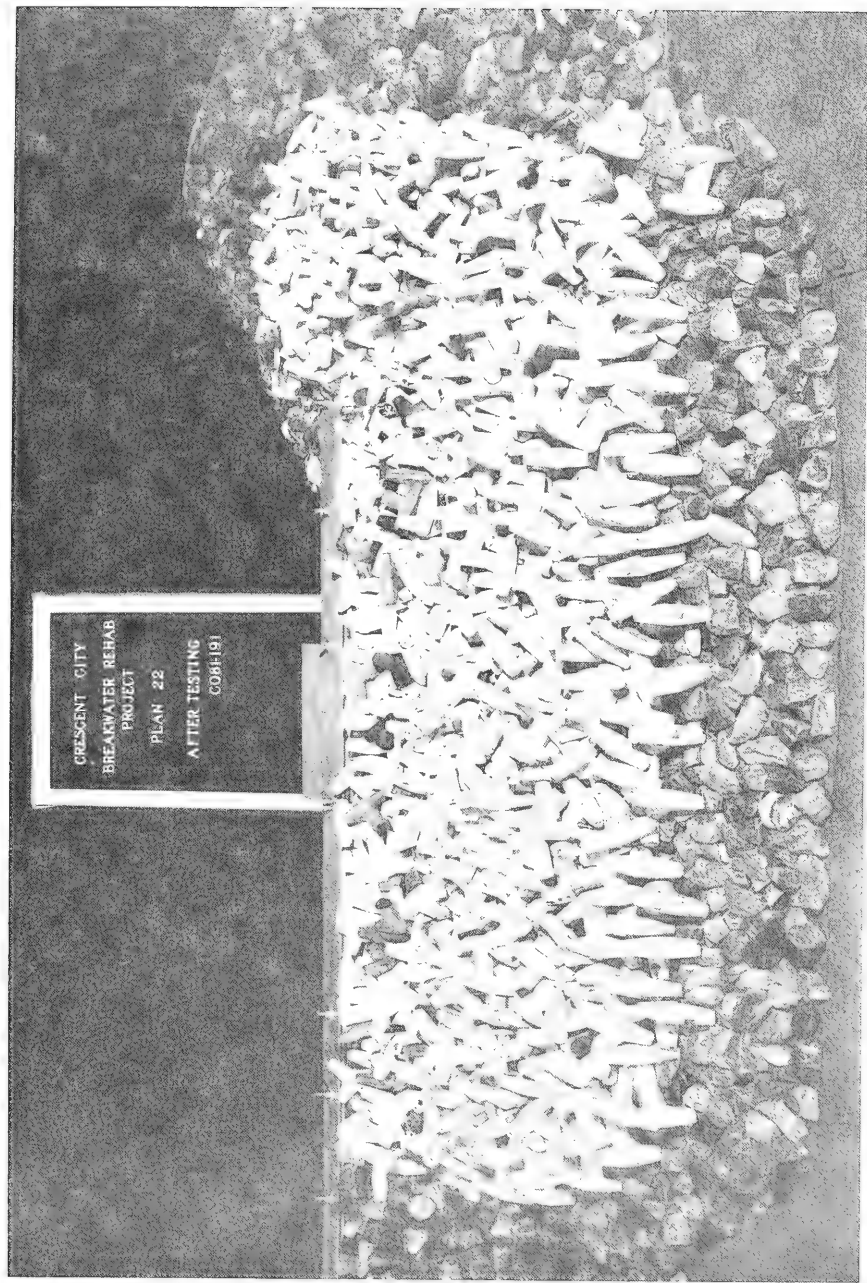


Photo 169. Sea-side view of Plan 22 after completion of abbreviated hydrograph



Photo 170. Seaward oblique view of Plan 22 after completion of abbreviated hydrograph

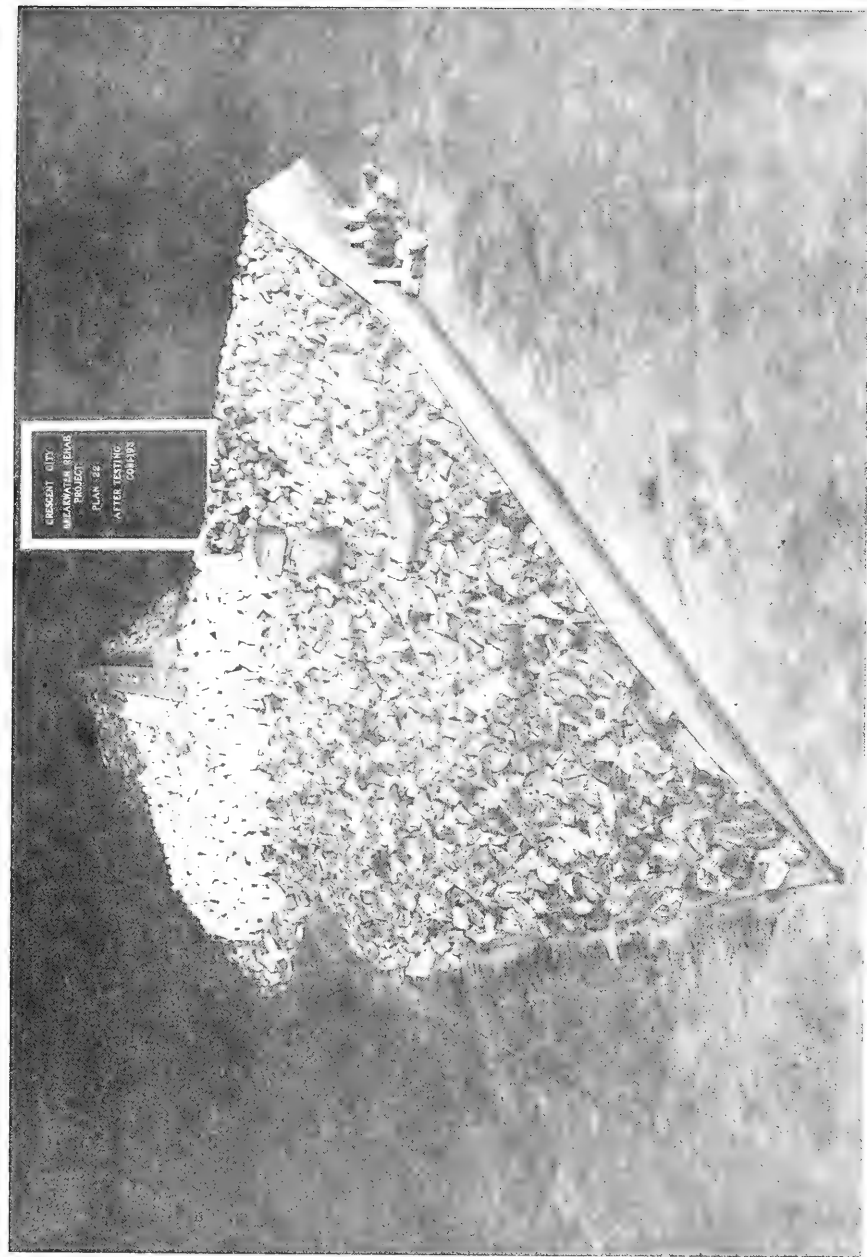


Photo 171. Seaward end view of Plan 22 after completion of abbreviated hydrograph

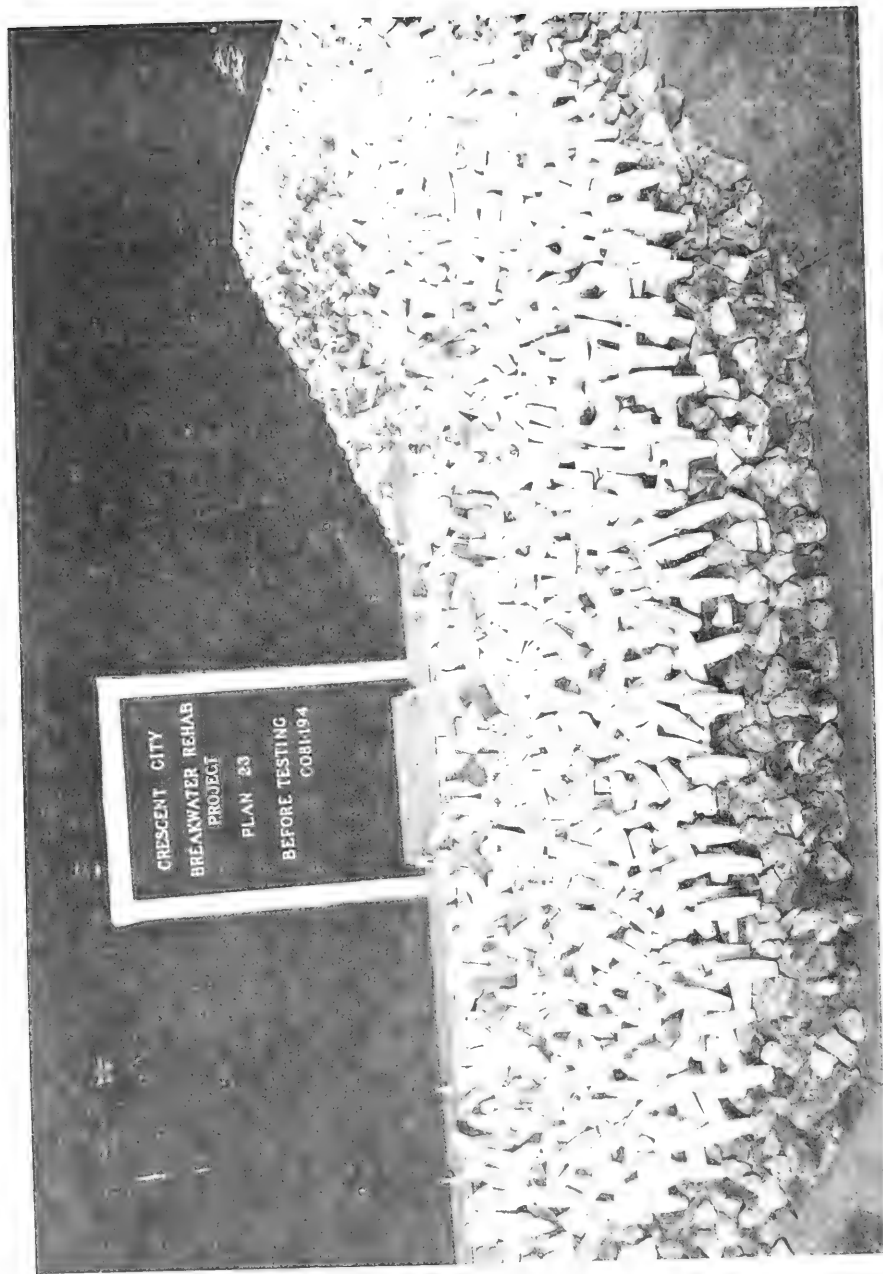


Photo 172. Sea-side view of Plan 23 before wave attack



Photo 173. Seaward oblique view of Plan 23 before wave attack

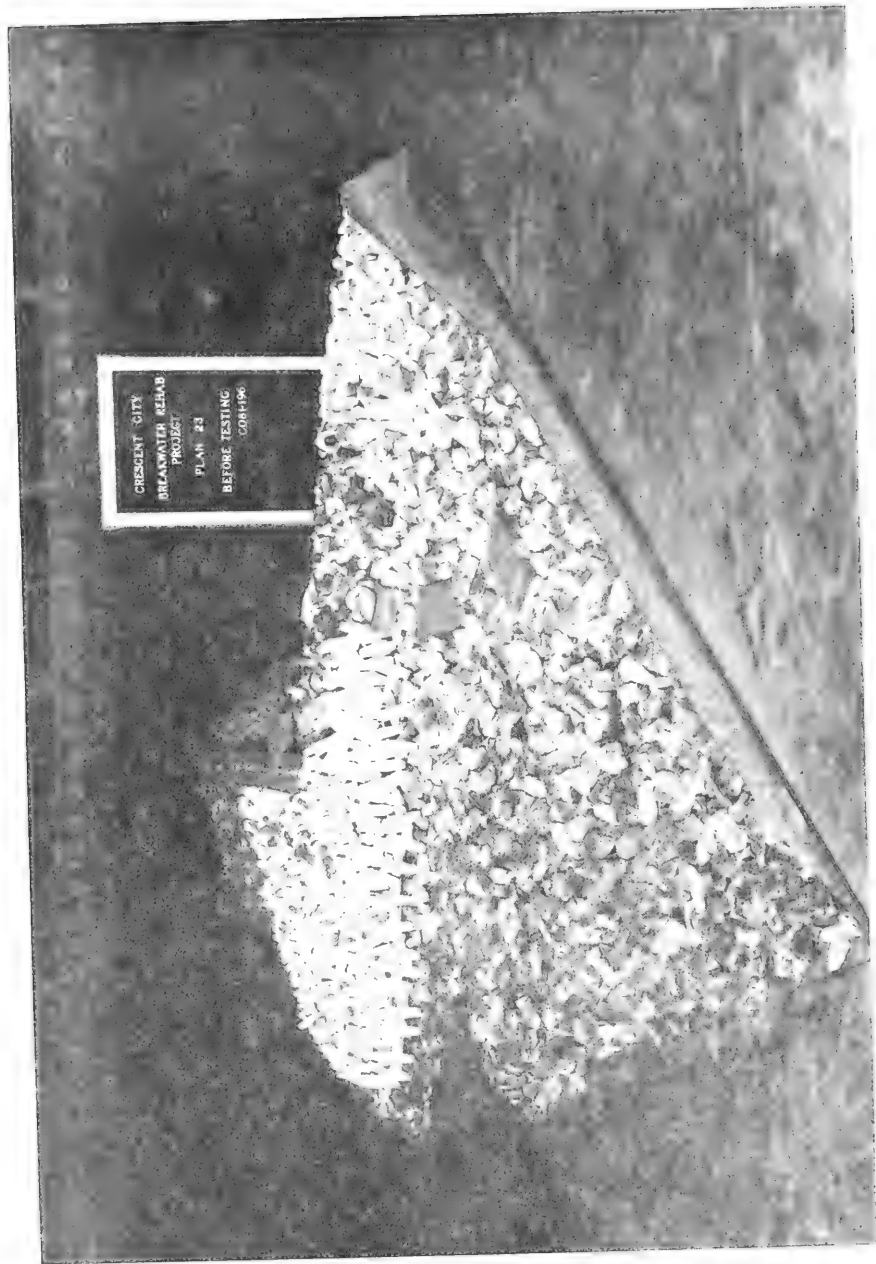
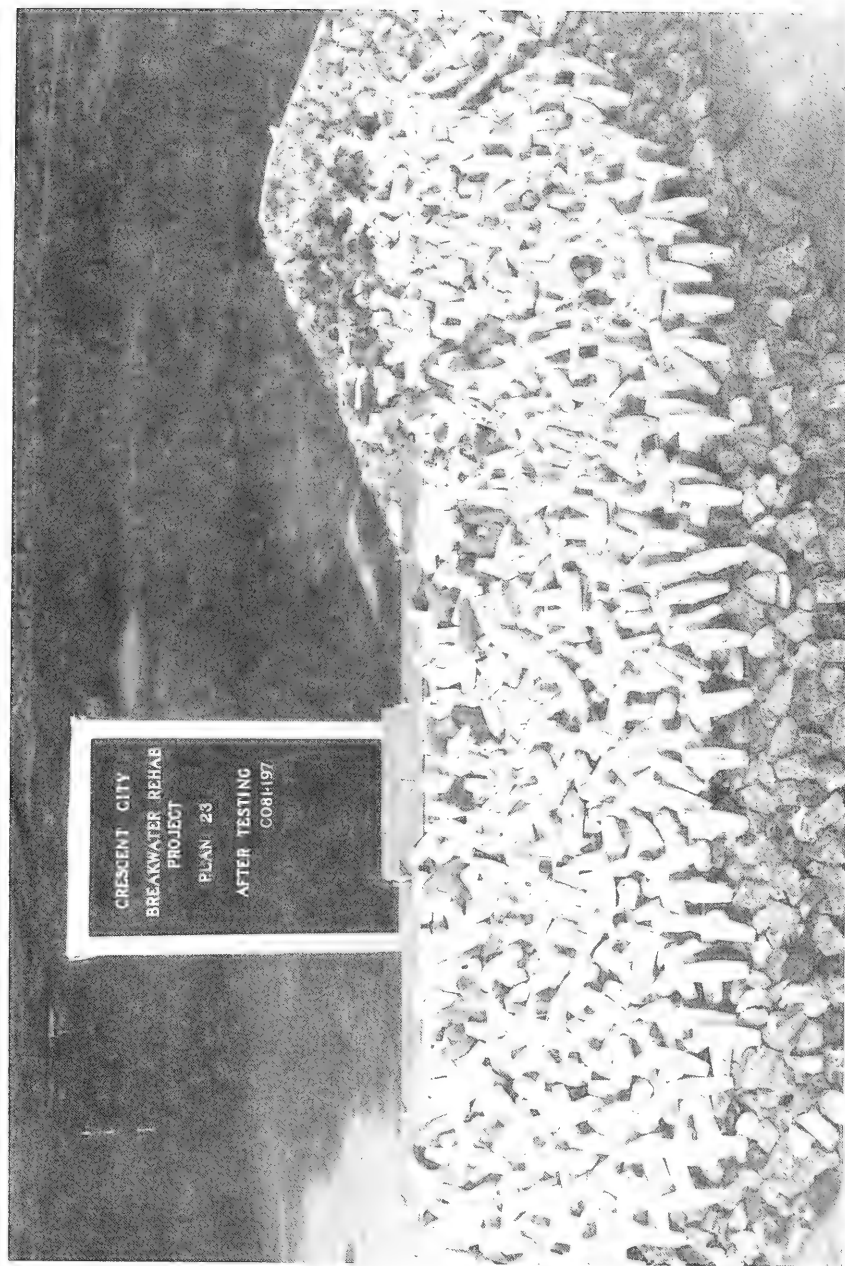


Photo 174. Seaward end view of Plan 23 before wave attack



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Photo 175. Sea-side view of Plan 23 after completion of abbreviated hydrograph



Photo 176. Seaward oblique view of Plan 23 after completion of abbreviated hydrograph



Photo 177. Seaward end view of Plan 23 after completion of abbreviated hydrograph

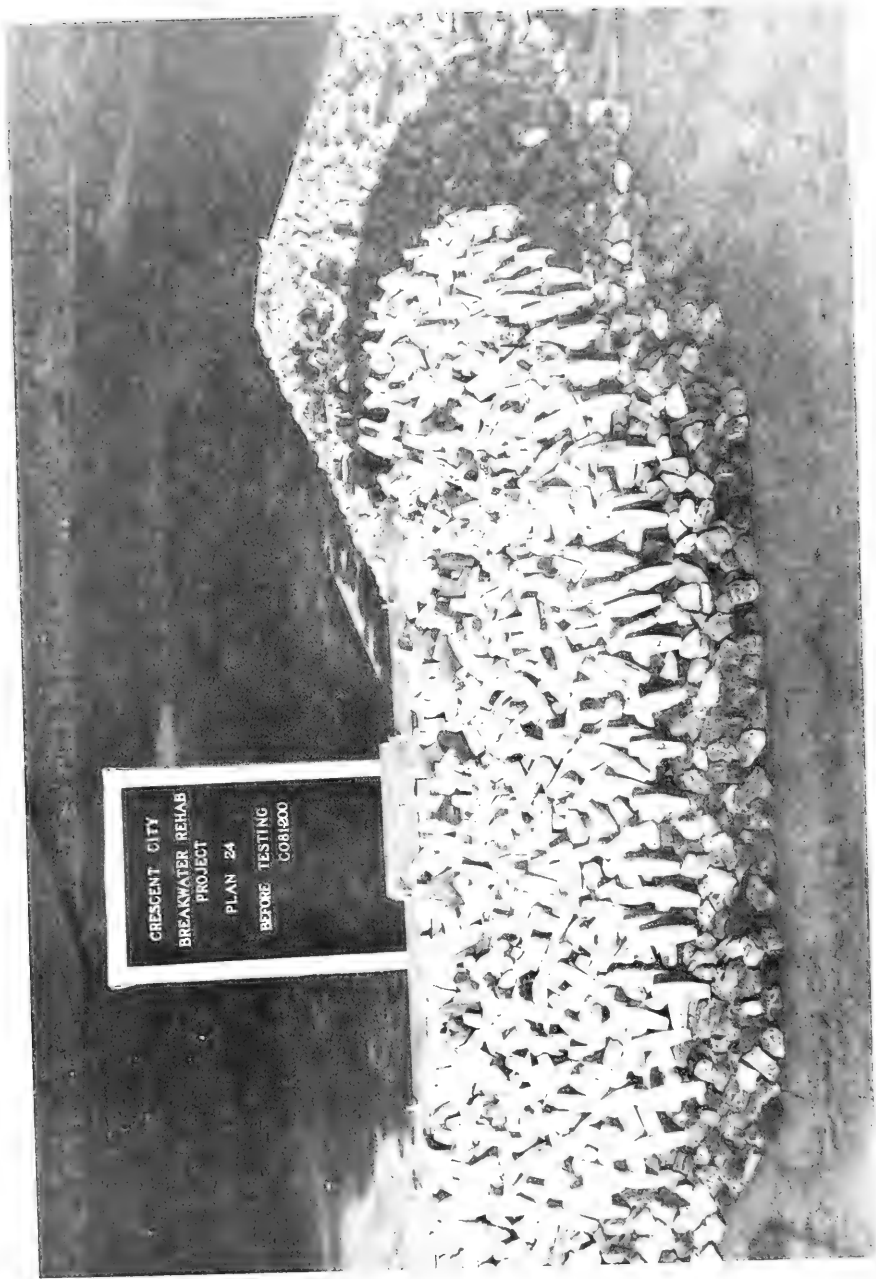


Photo 178. Sea-side view of Plan 24 before wave attack



Photo 179. Seaward oblique view of Plan 24 before wave attack



Photo 180. Seaward end view of Plan 24 before wave attack

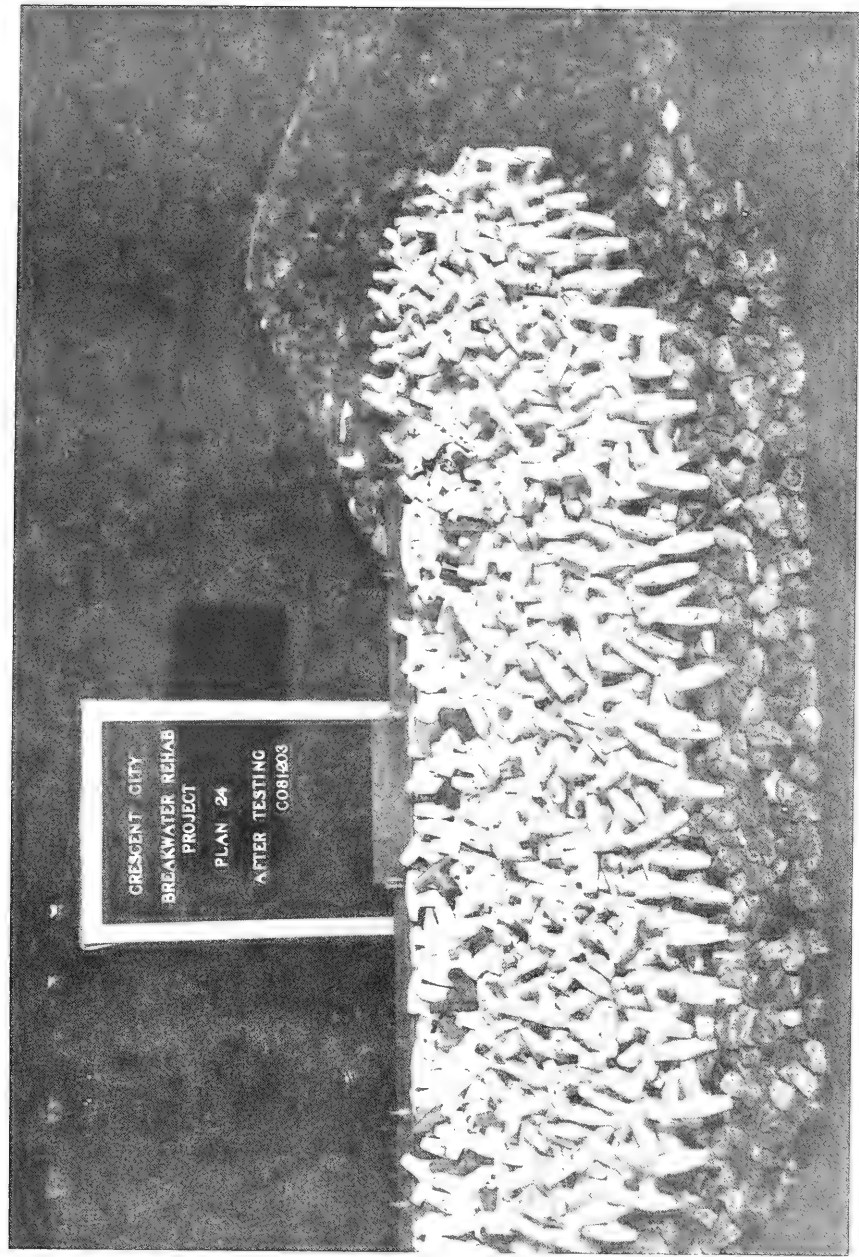


Photo 181. Sea-side view of Plan 24 after completion of abbreviated hydrograph



Photo 182. Seaward oblique view of Plan 24 after completion of abbreviated hydrograph

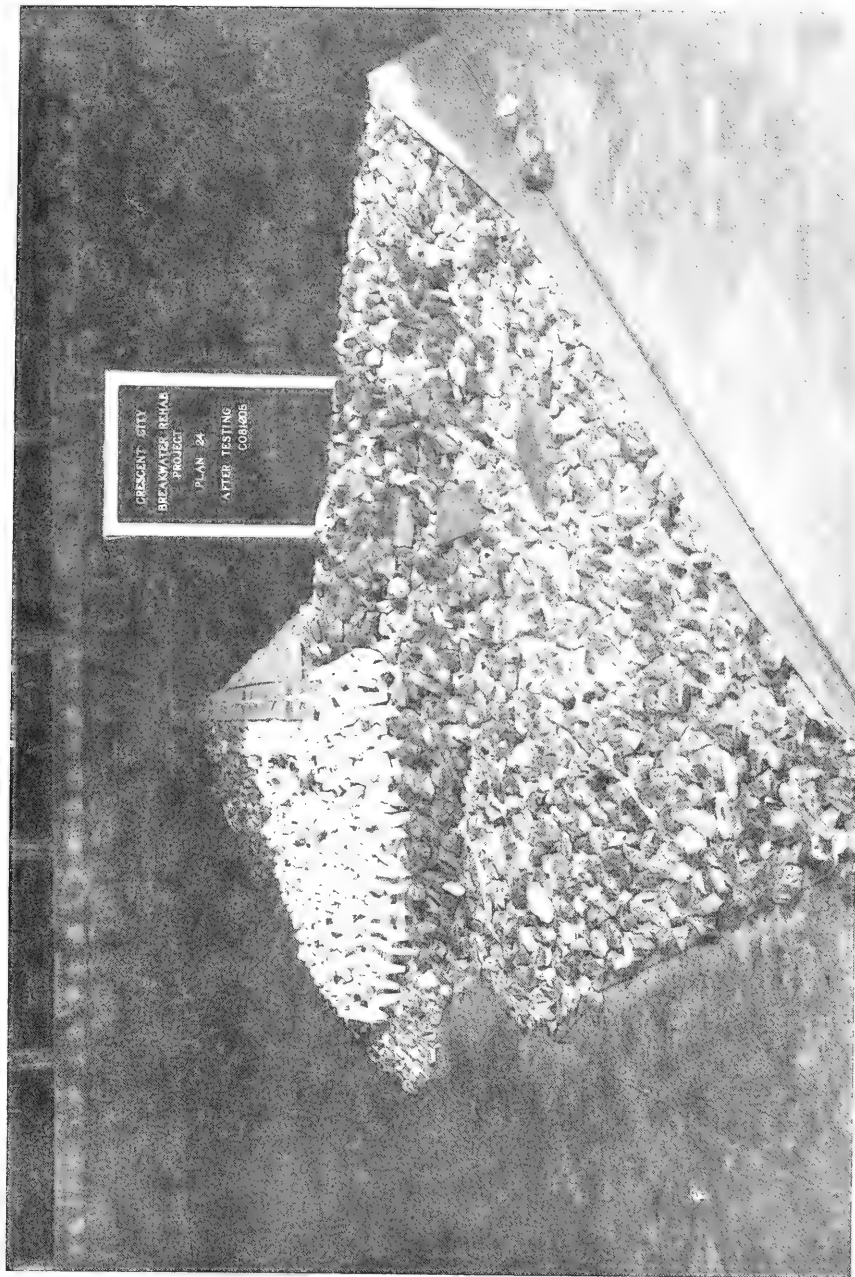


Photo 183. Seaward end view of Plan 24 after completion of abbreviated hydrograph

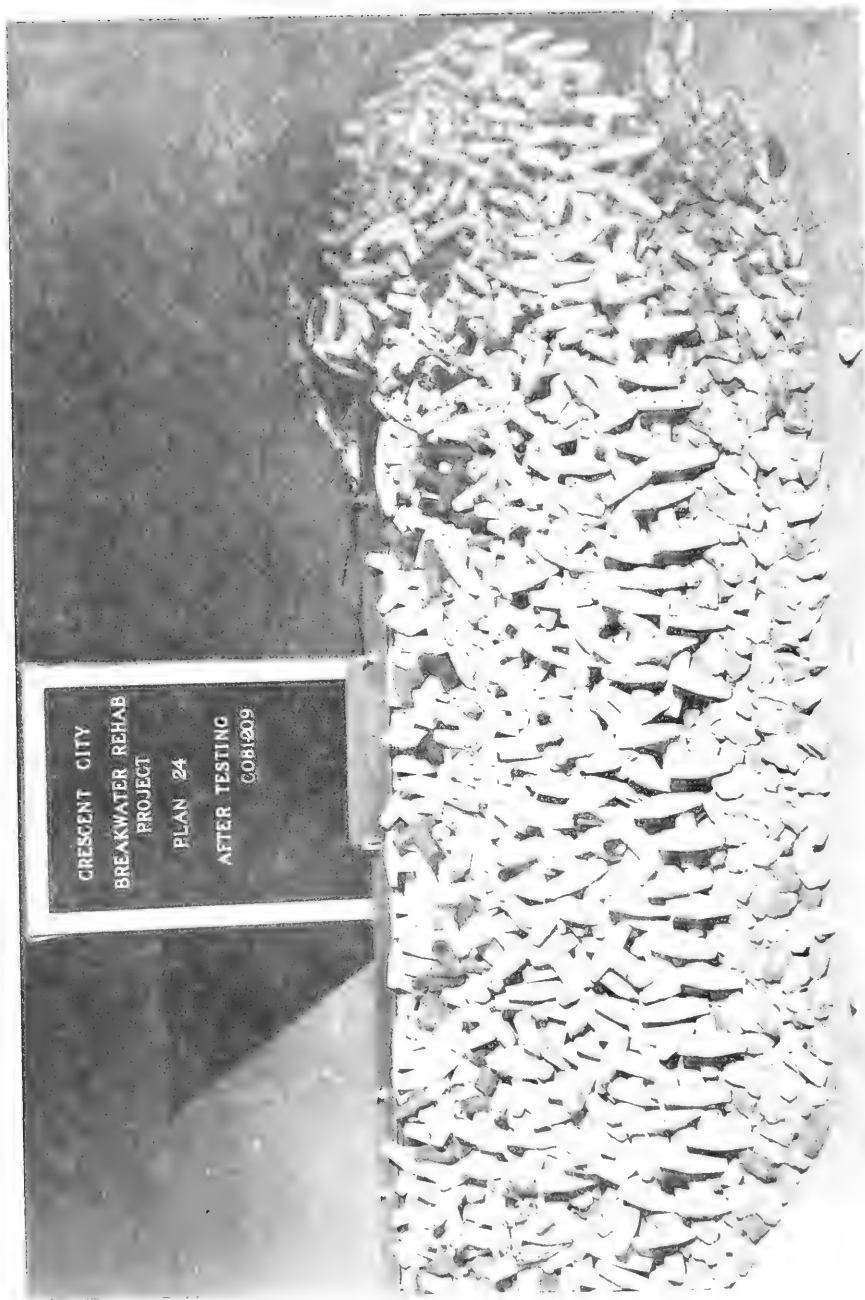


Photo 184. Sea-side view of Plan 24 after completion of Hydrograph A



Photo 185. Seaward oblique view of Plan 24 after completion of Hydrograph A

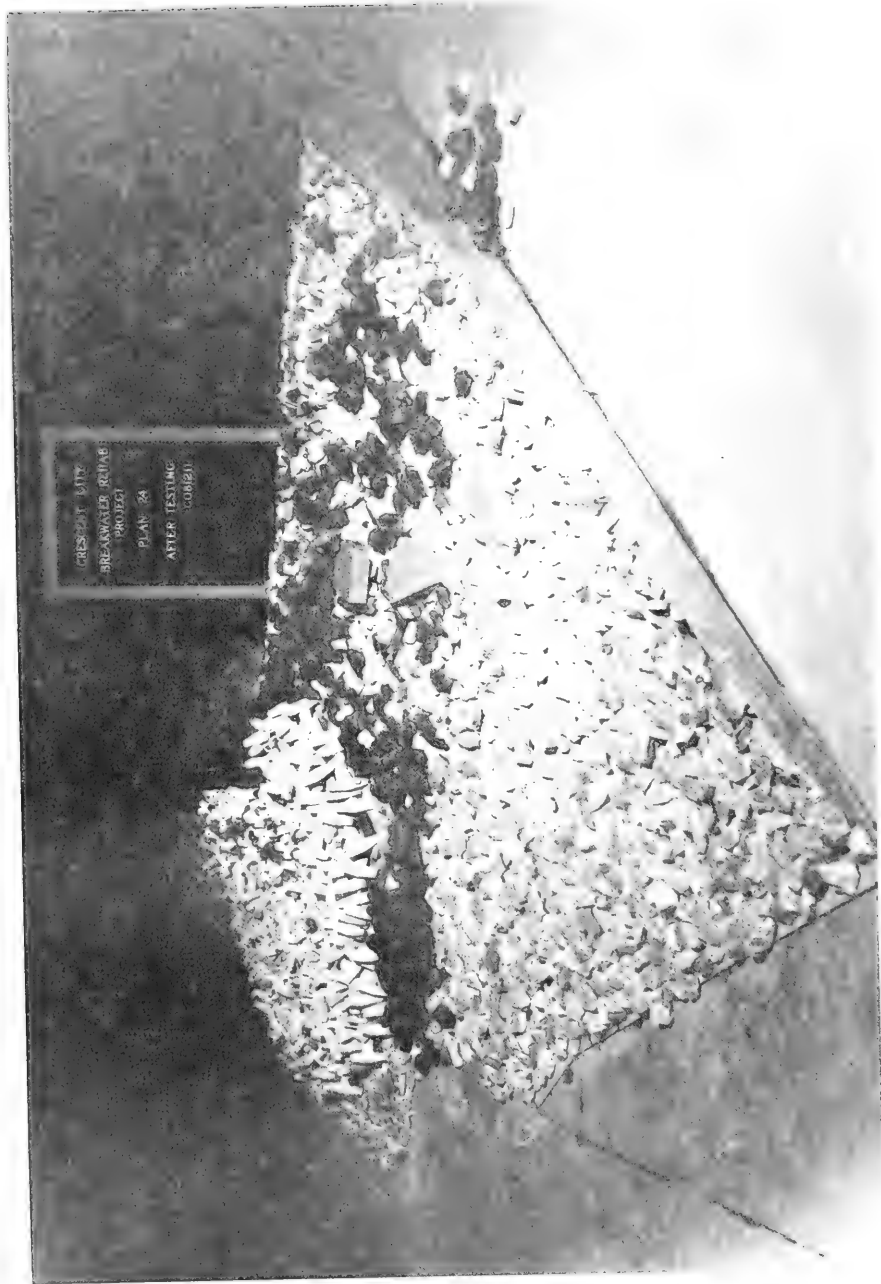


Photo 186. Seaward end view of Plan 24 after completion of Hydrograph A



Photo 187. Sea-side view of Plan 24 after cumulative testing of Hydrographs A and B



Photo 188. Seaward oblique view of Plan 24 after cumulative testing of Hydrographs A and B



Photo 189. Seaward end view of Plan 24 after cumulative testing of Hydrographs A and B

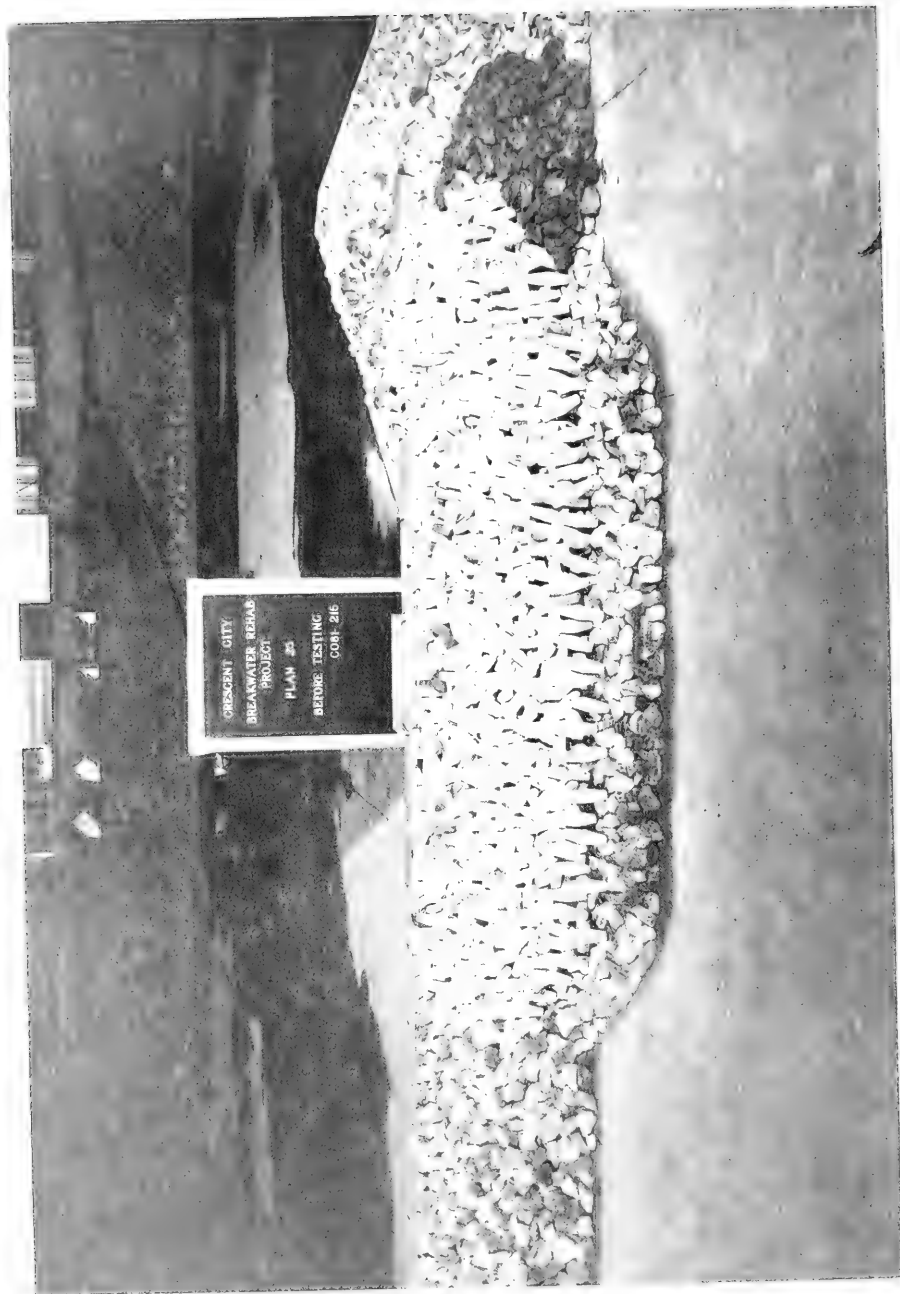


Photo 190. Sea-side view of Plan 25 before wave attack



Photo 191. Seaward oblique view of Plan 25 before wave attack



Photo 192. Seaward end view of Plan 25 before wave attack

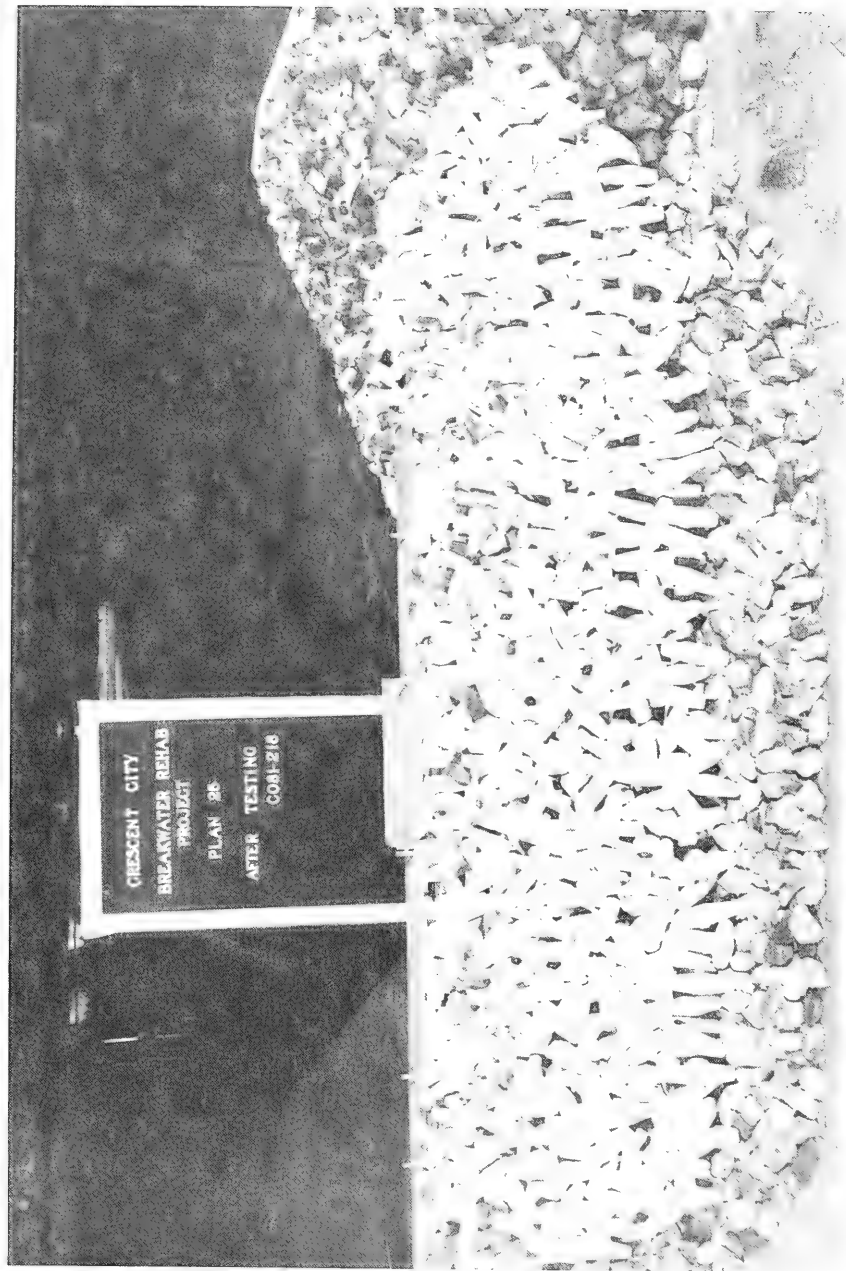


Photo 193. Sea-side view of Plan 25 after completion of abbreviated hydrograph



Photo 194. Seaward oblique view of Plan 25 after completion of abbreviated hydrograph



Photo 195. Seaward end view of Plan 25 after completion of abbreviated hydrograph

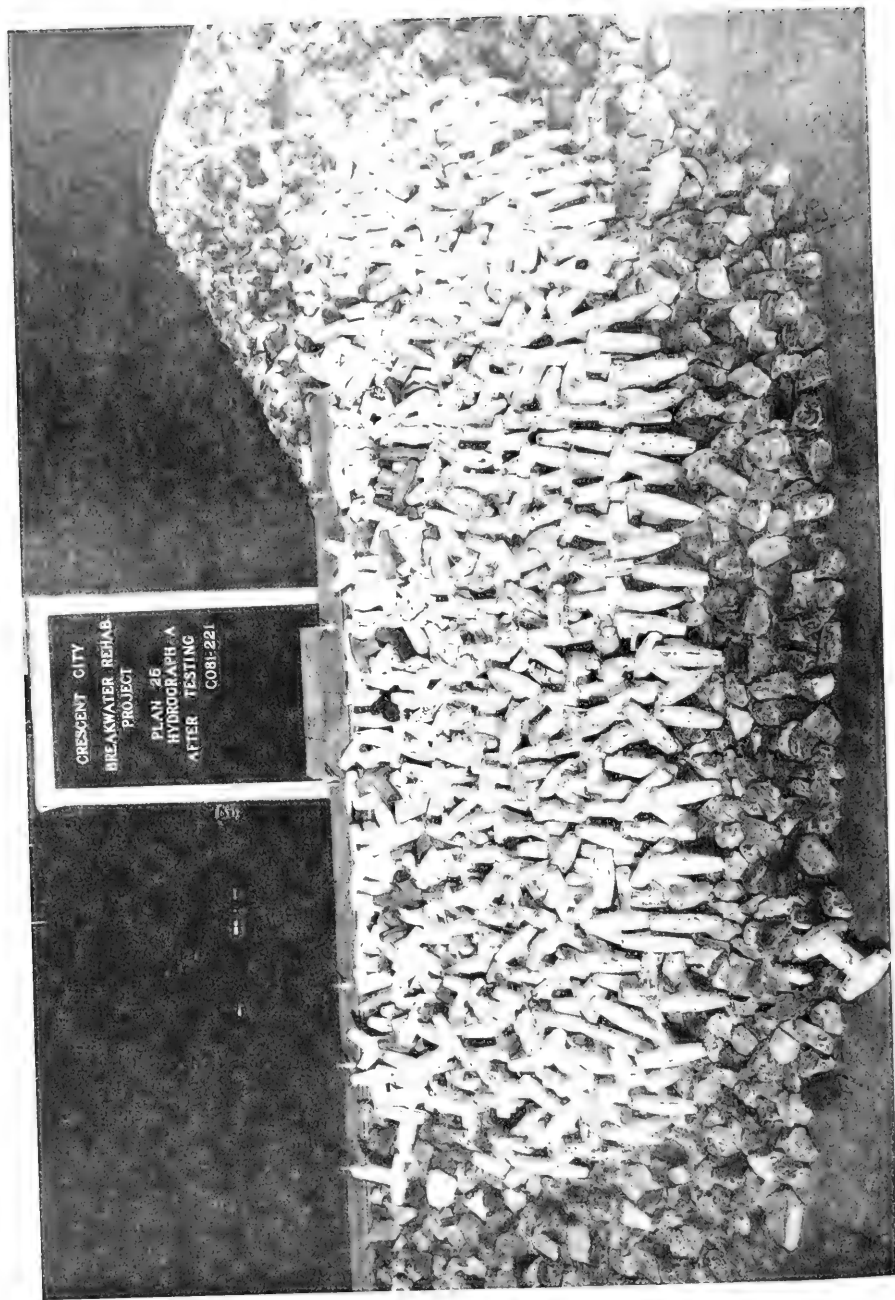


Photo 196. Sea-side view of Plan 25 after completion of Hydrograph A

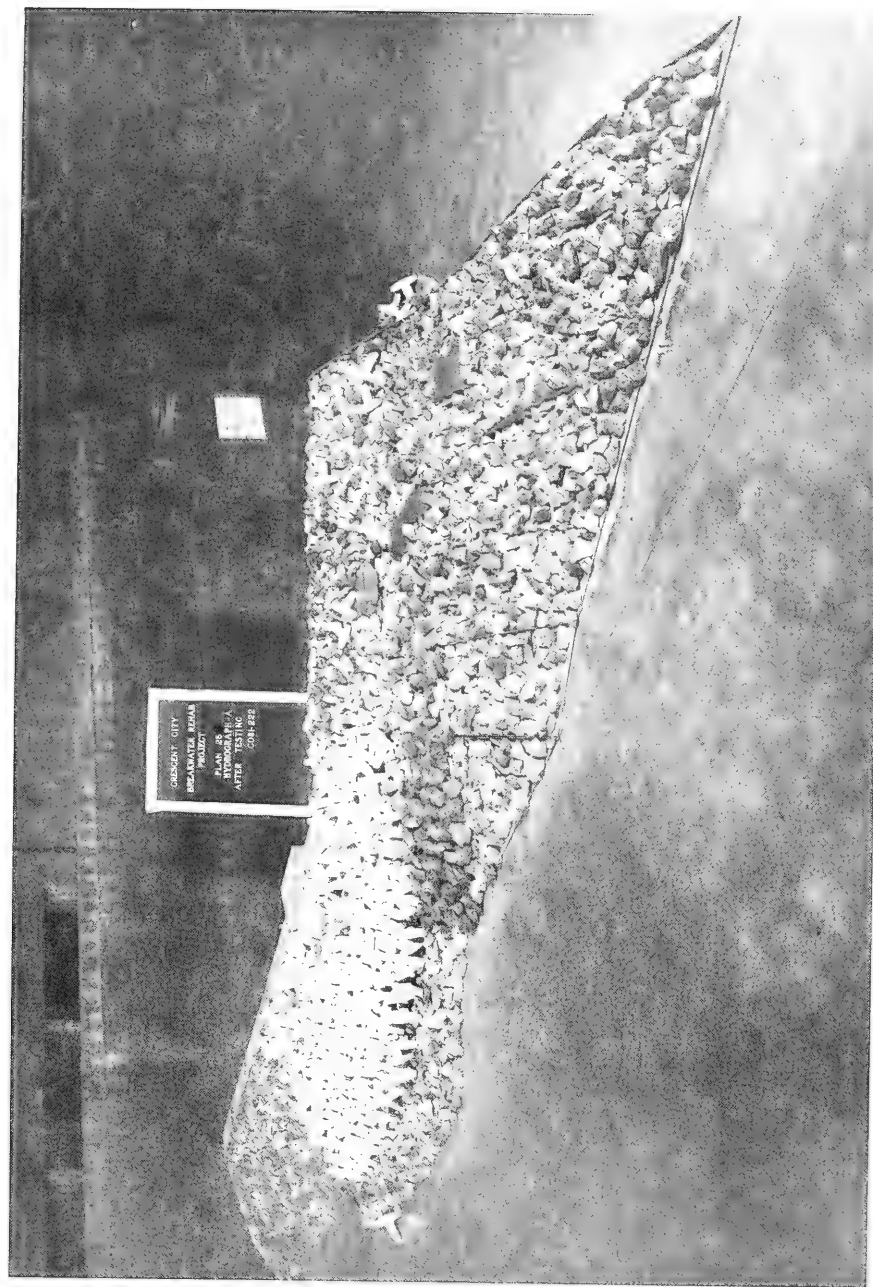


Photo 197. Seaward oblique view of Plan 25 after completion of Hydrograph A



Photo 198. Seaward end view of Plan 25 after completion of Hydrograph A

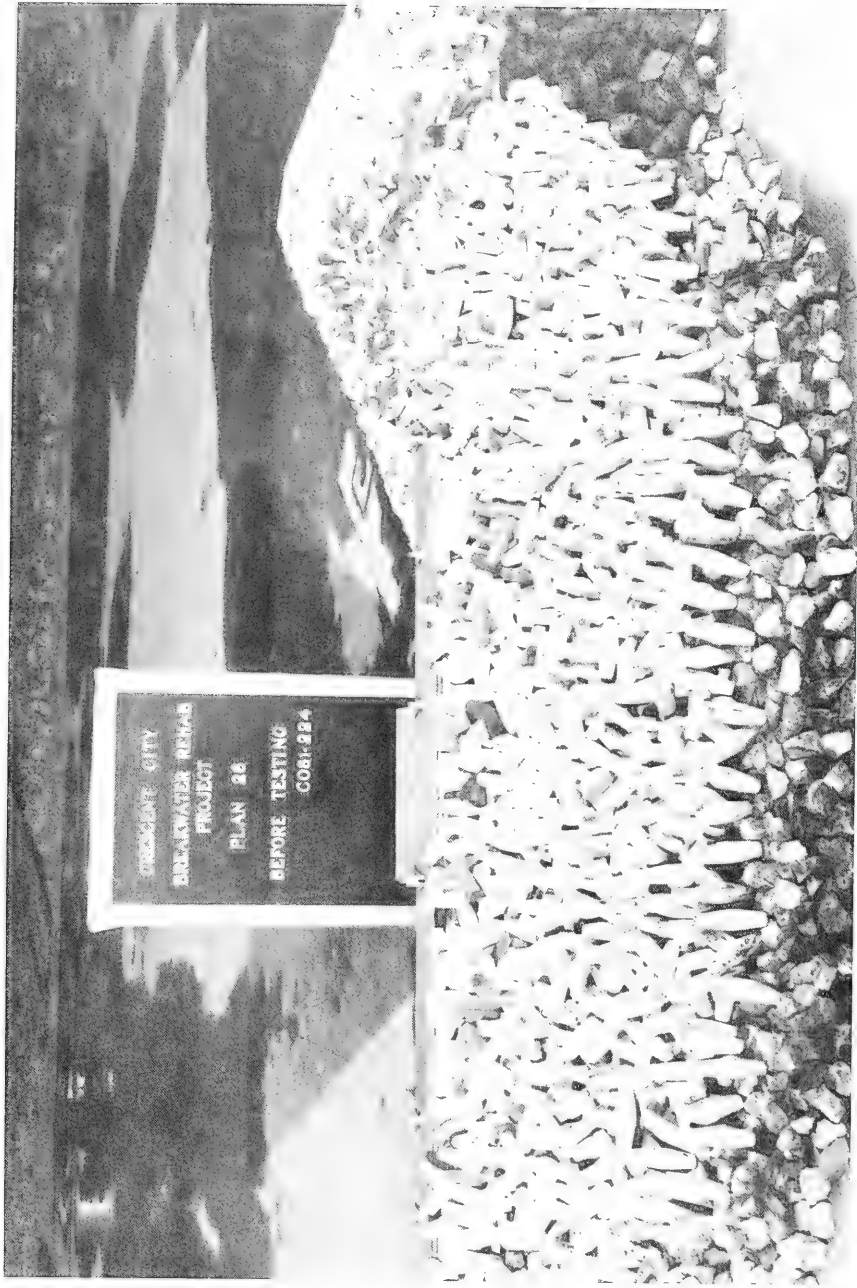


Photo 199. Sea-side view of Plan 26 before wave attack



Photo 200. Seaward oblique view of Plan 26 before wave attack



Photo 201. Seaward end view of Plan 26 before wave attack

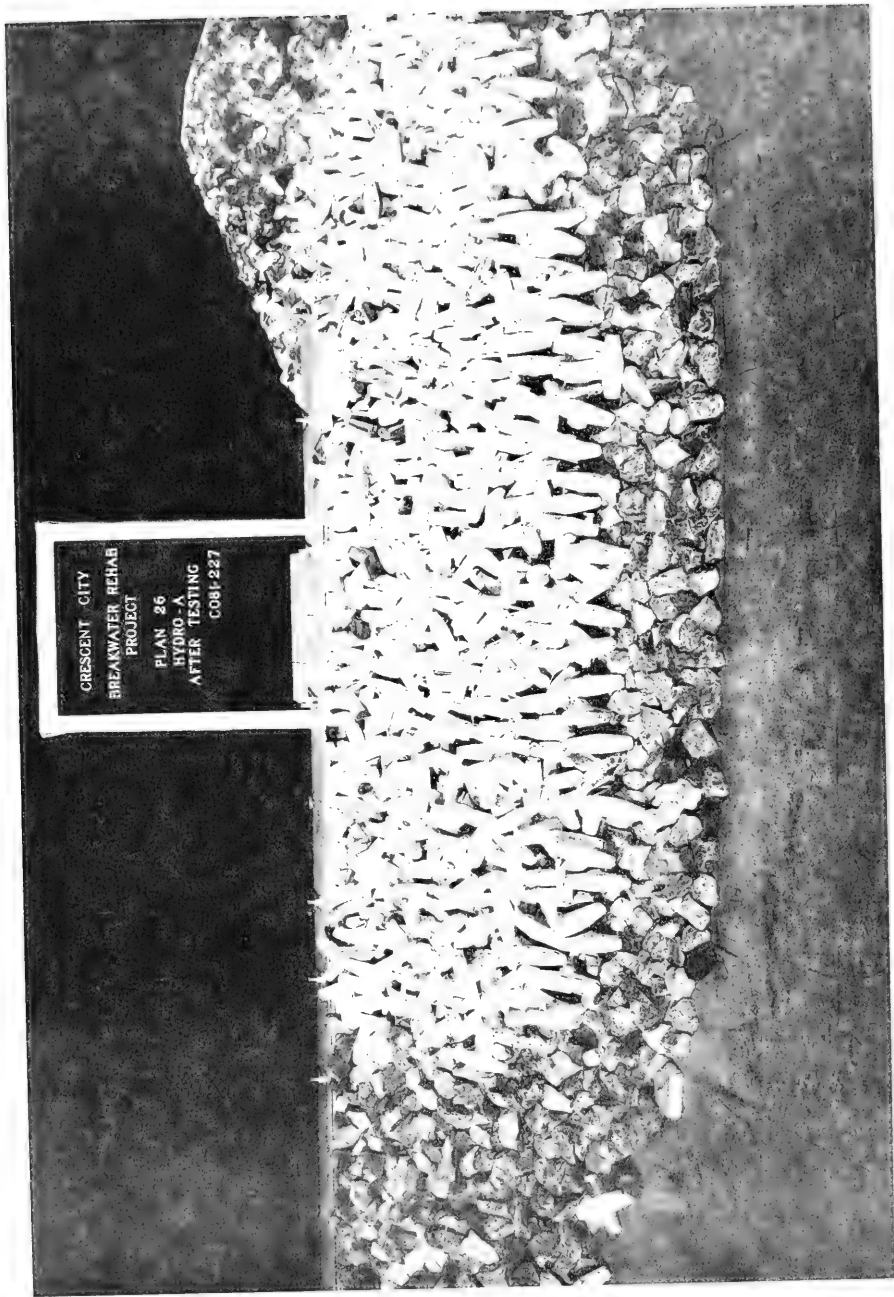


Photo 202. Sea-side view of Plan 26 after completion of Hydrograph A

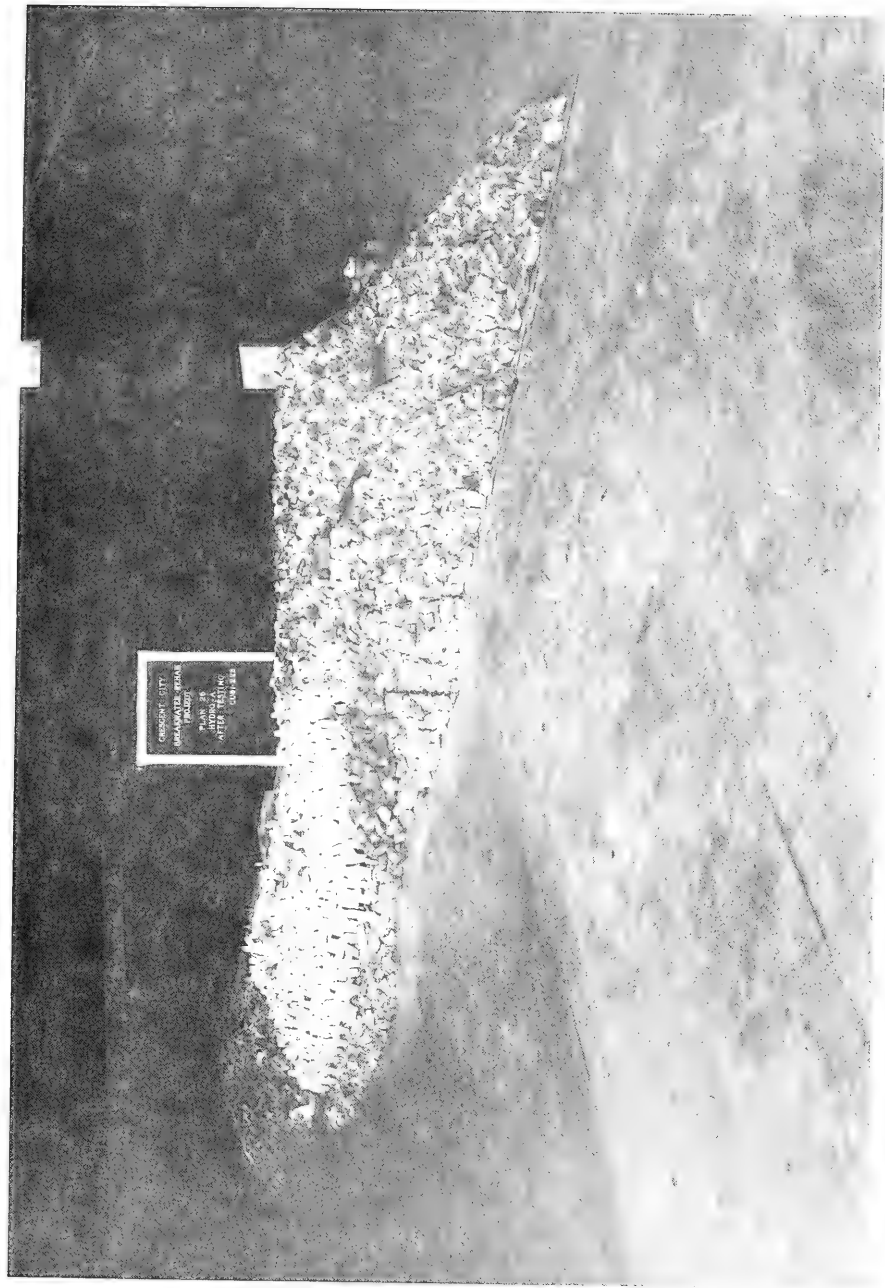


Photo 203. Seaward oblique view of Plan 26 after completion of Hydrograph A



Photo 204. Seaward end view of Plan 26 after completion of Hydrograph A

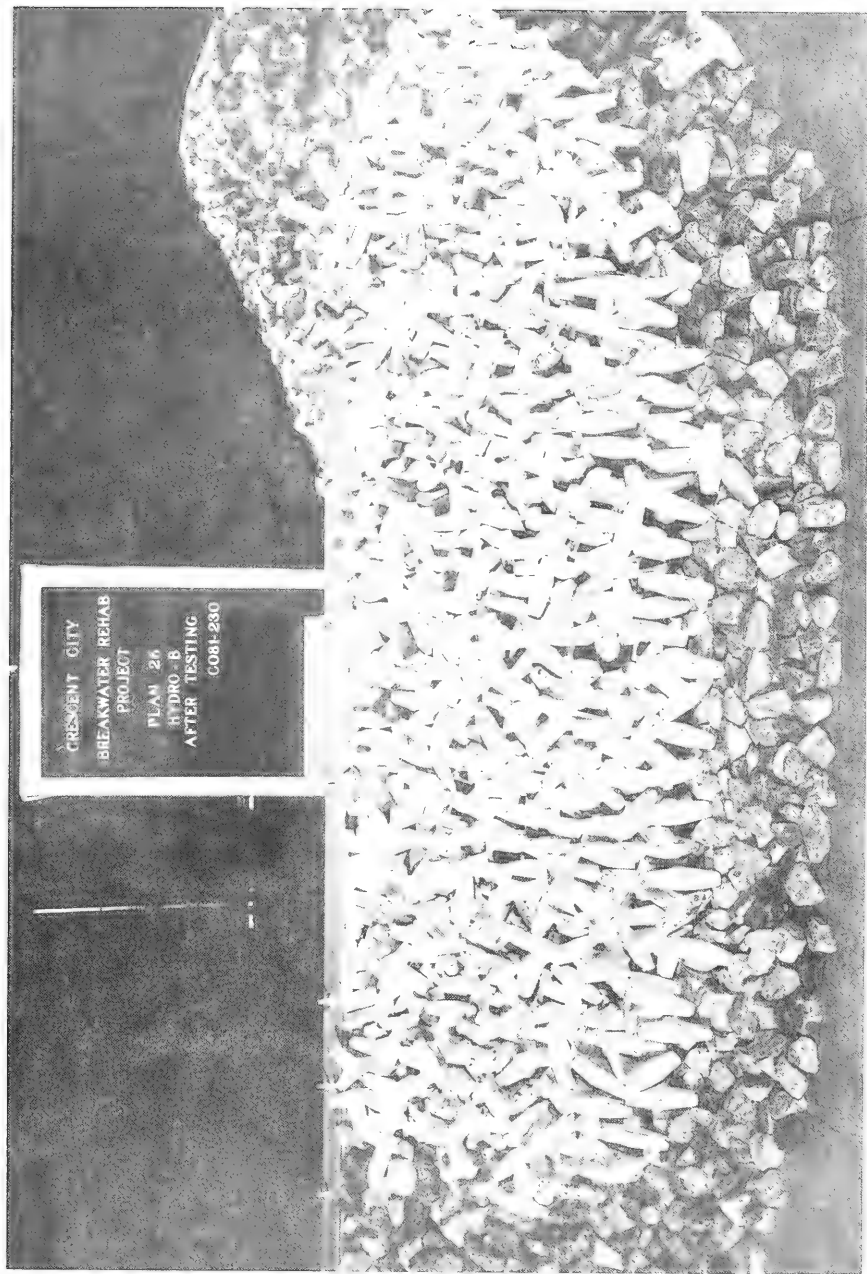


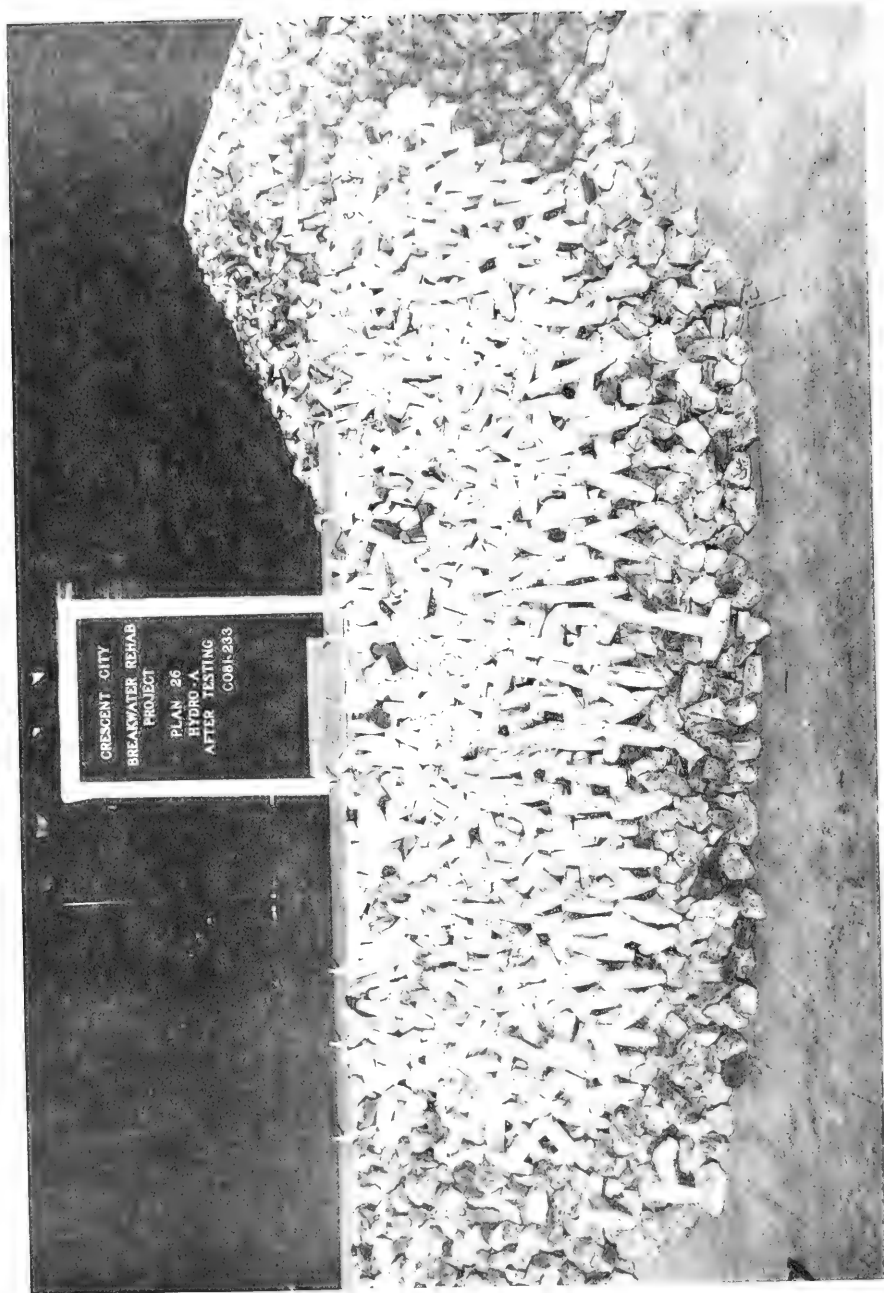
Photo 205. Sea-side view of Plan 26 after cumulative testing of Hydrographs A and B



Photo 206. Seaward oblique view of Plan, 26 after cumulative testing of Hydrographs A and B



Photo 207. Seaward end view of Plan 26 after cumulative testing of Hydrographs A and B

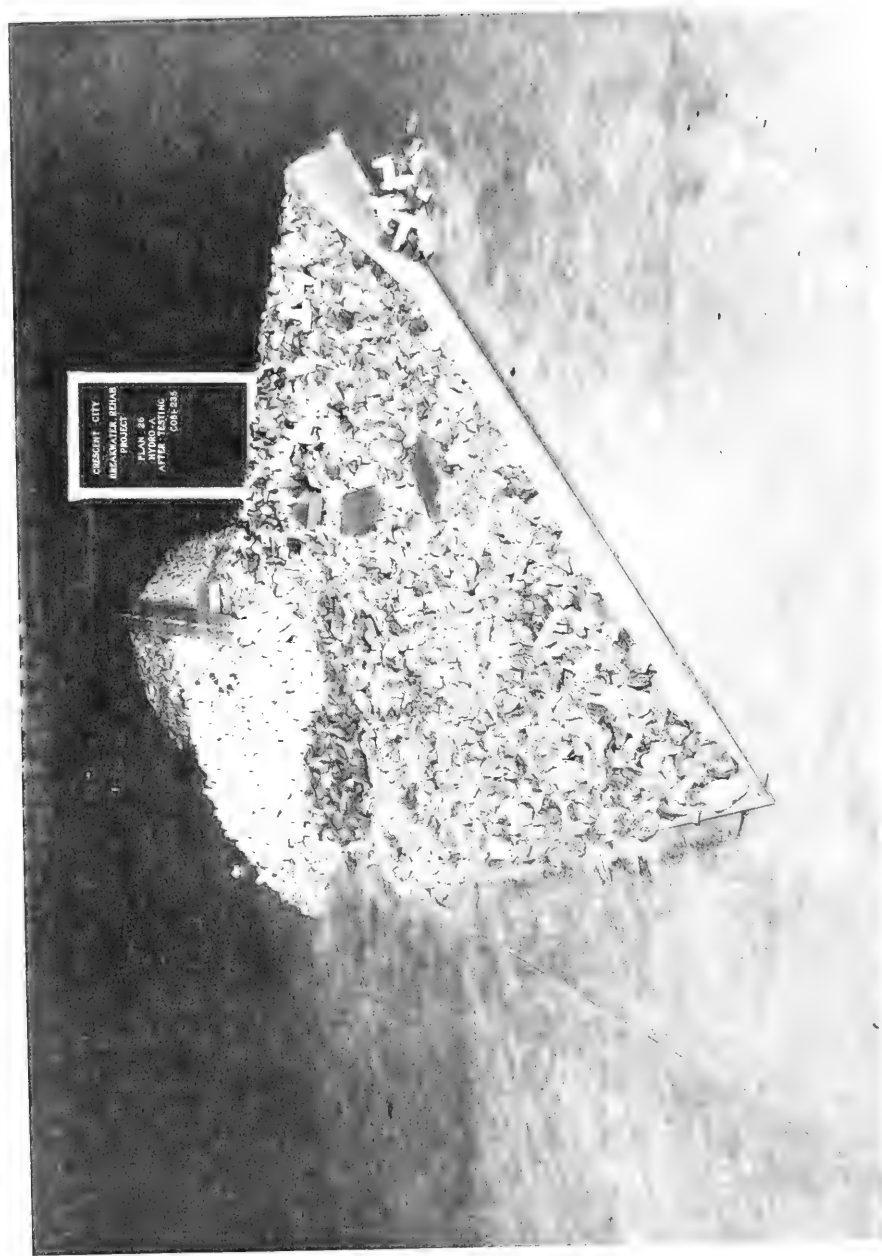


CRESCENT CITY
BREAKWATER REHAB
PROJECT
PLAN 26
HYDRO-A
AFTER TESTING
CON-283

Photo 208. Sea-side view of Plan 26 after first repeat test with Hydrograph A



Photo 209. Seaward oblique view of Plan 26 after first repeat test with Hydrograph A



CRESSENT CITY
RECAVATEUR PERMANENT
PLAN 26
HYDRO-A
AFTER TESTING
607-236

Photo 210. Seaward end view of Plan 26 after first repeat test with Hydrograph A

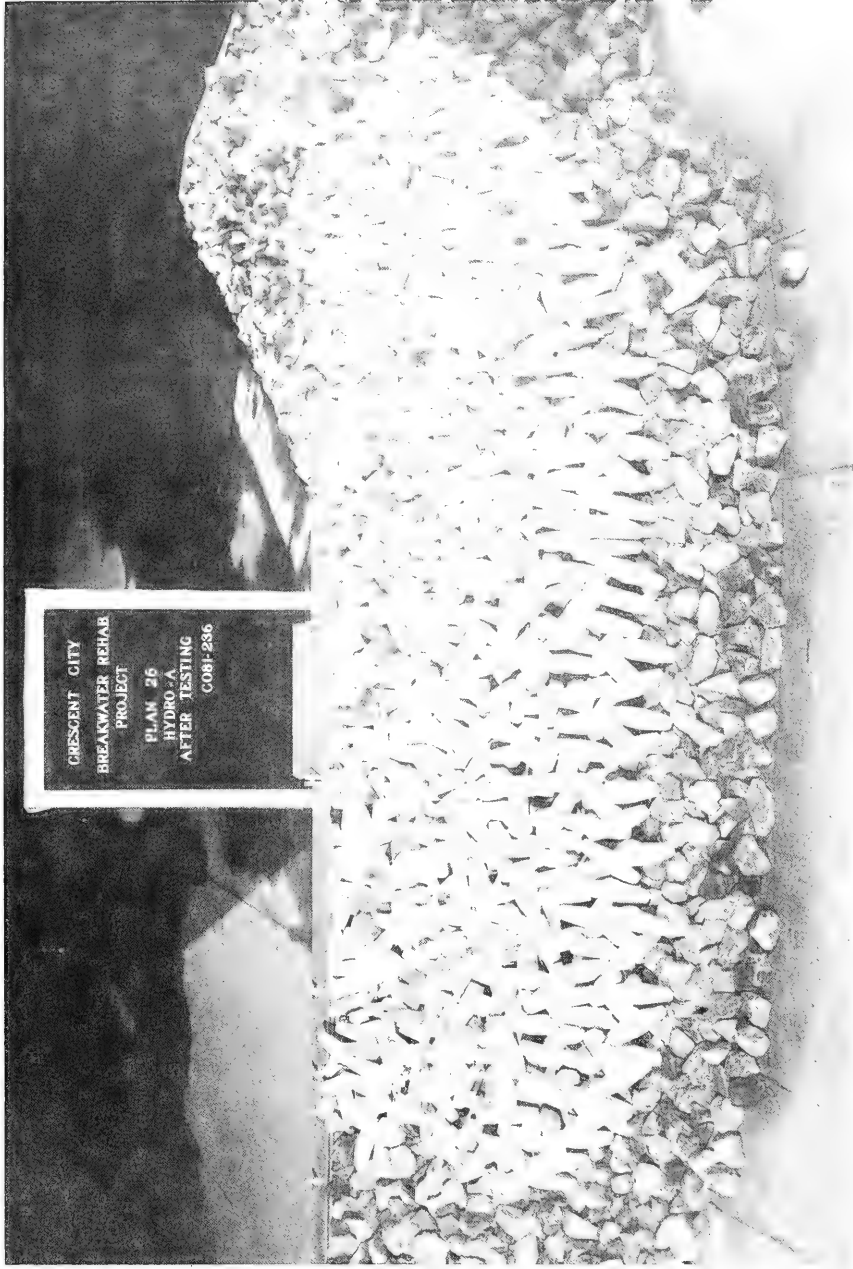


Photo 211. Sea-side view of Plan 26 after second repeat test with Hydrograph A



CORRECTION CITY
MARSHALLS ISLANDS
PROJECT
PLAN 26
HYDROGRAPHIC
ALTIMETER 5048.57

Photo 212. Seaward oblique view of Plan 26 after second repeat test with Hydrograph A



Photo 213. Seaward end view of Plan 26 after second repeat test with Hydrograph A

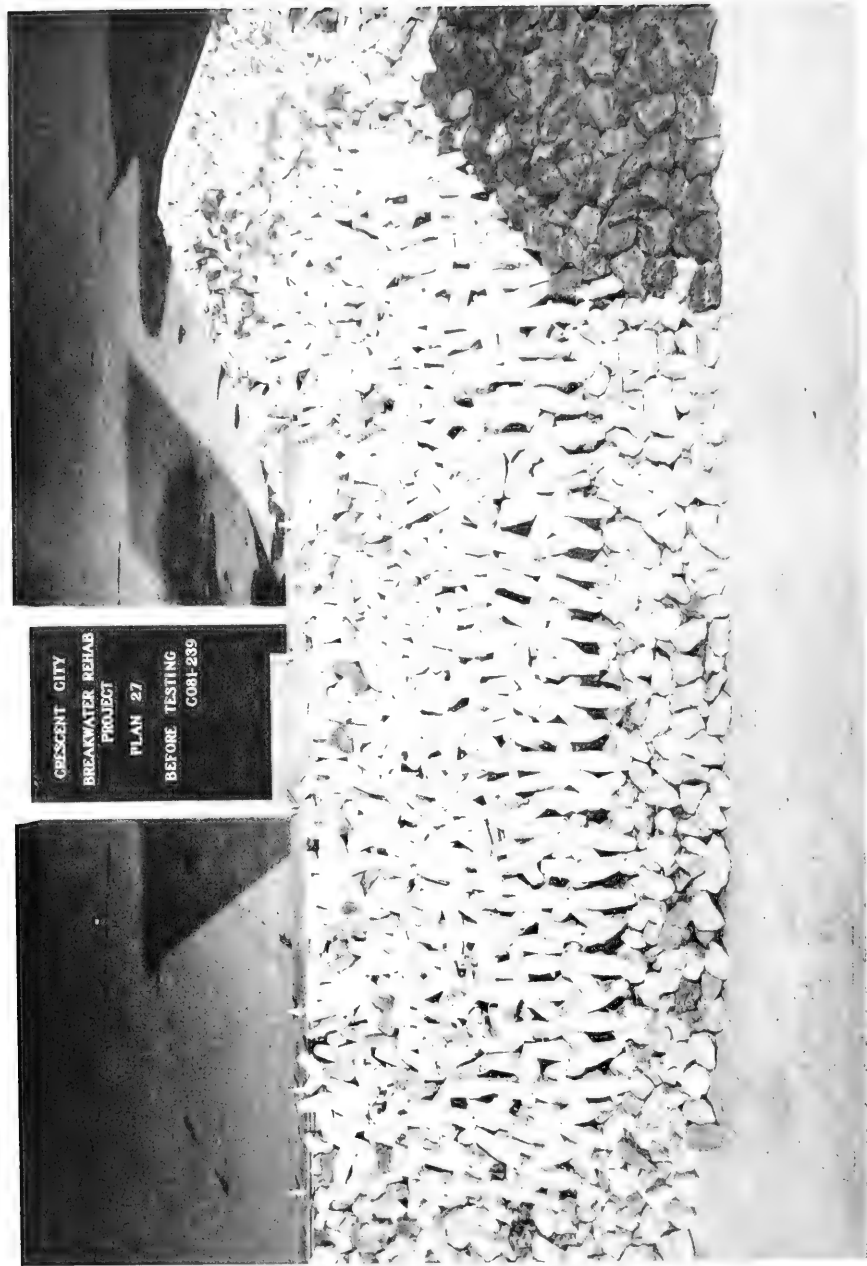


Photo 214. Sea-side view of Plan 27 before wave attack



Photo 215. Seaward oblique view of Plan 27 before wave attack



CHICAGO CITY
REARVIEW MOUNT
14.5 17
REAR VIEWING
COM-24

Photo 216. Seaward end view of Plan 27 before wave attack

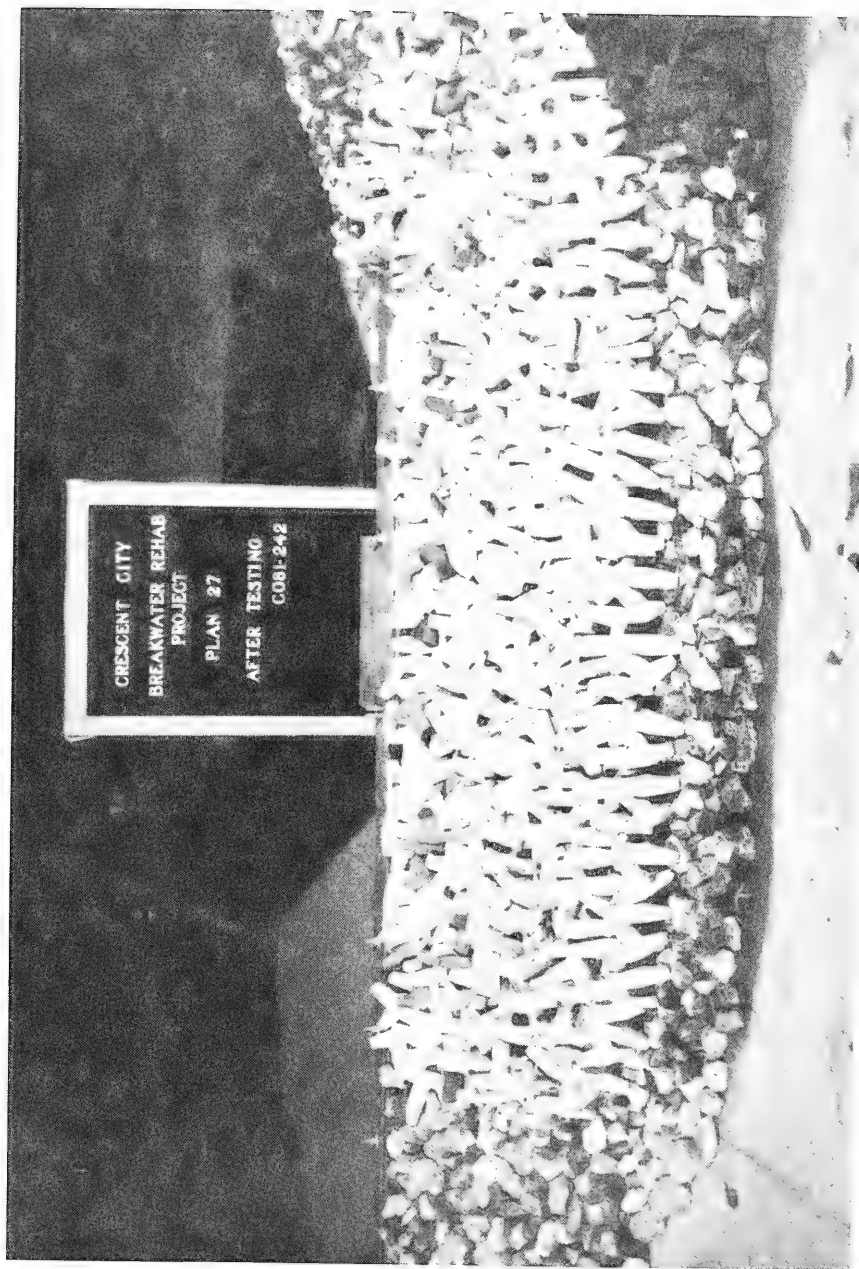


Photo 217. Sea-side view of Plan 27 after completion of abbreviated hydrograph



Photo 218. Seaward oblique view of Plan 27 after completion of abbreviated hydrograph



Photo 219. Seaward end view of Plan 27 after completion of abbreviated hydrograph

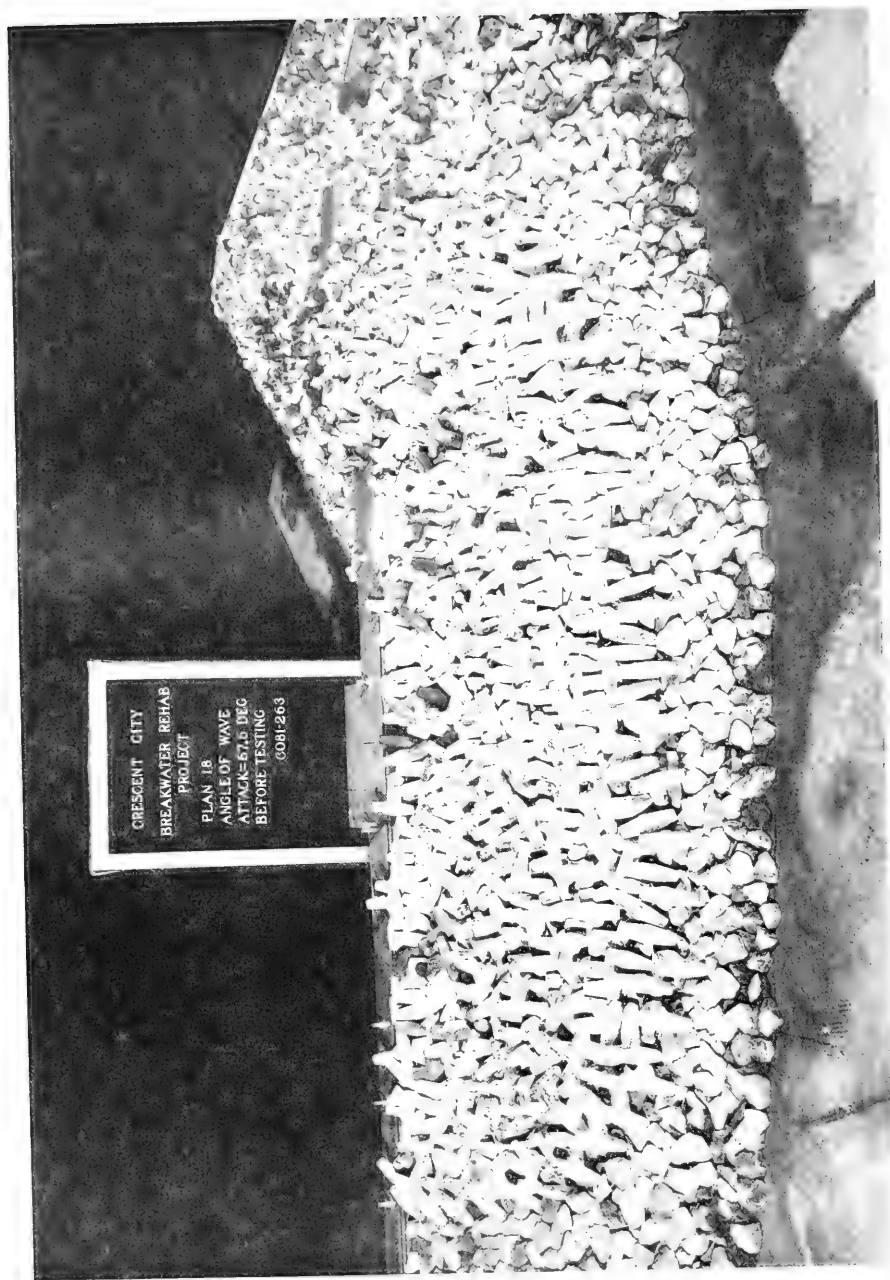


Photo 220. Sea-side view of Plan 18 before wave attack after modification to shoreward transition; 67.5-deg angle of wave attack

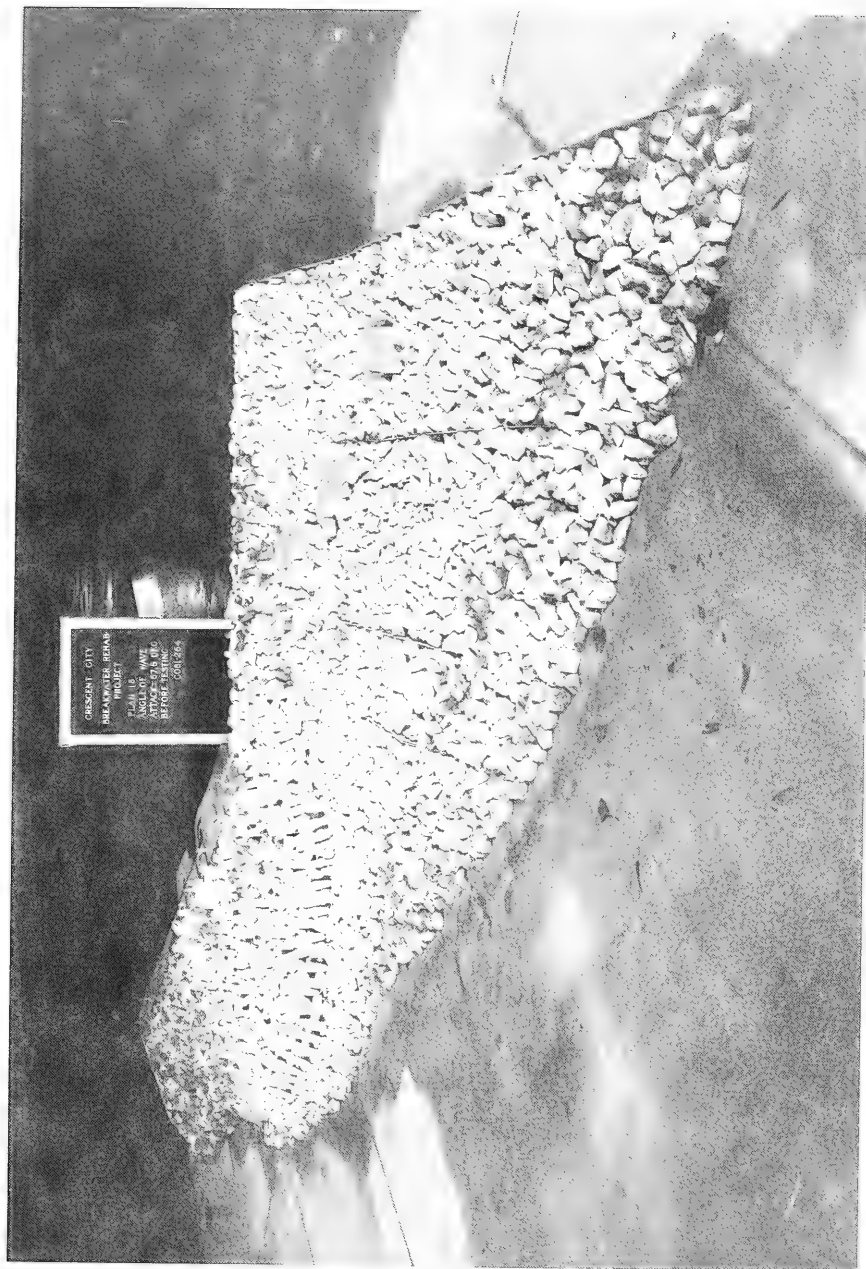


Photo 221. Seaward oblique view of Plan 18 before wave attack after modification
to shoreward transition; 67.5-deg angle of wave attack

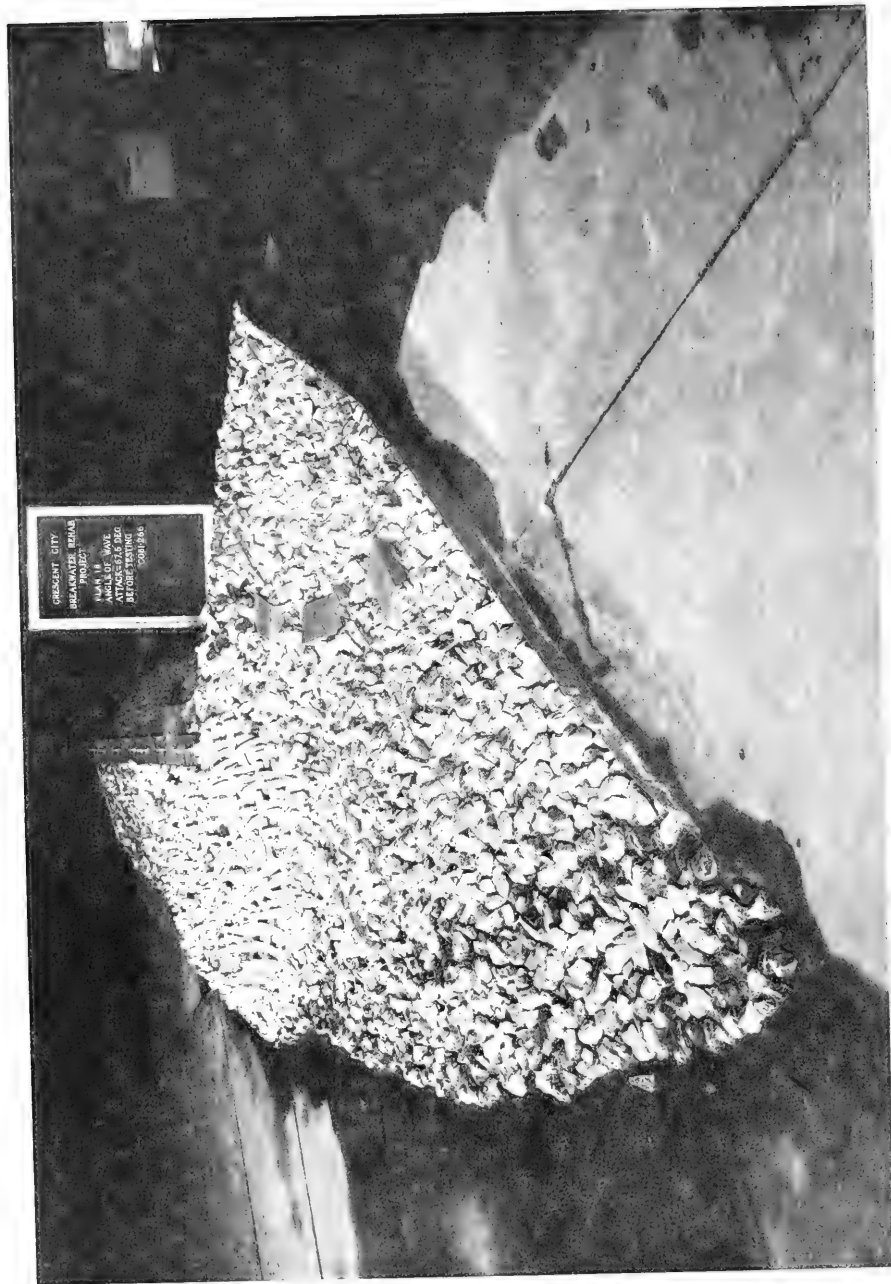


Photo 222. Sea-side end view of Plan 18 before wave attack after modification to shoreward transition; 67.5-deg angle of wave attack

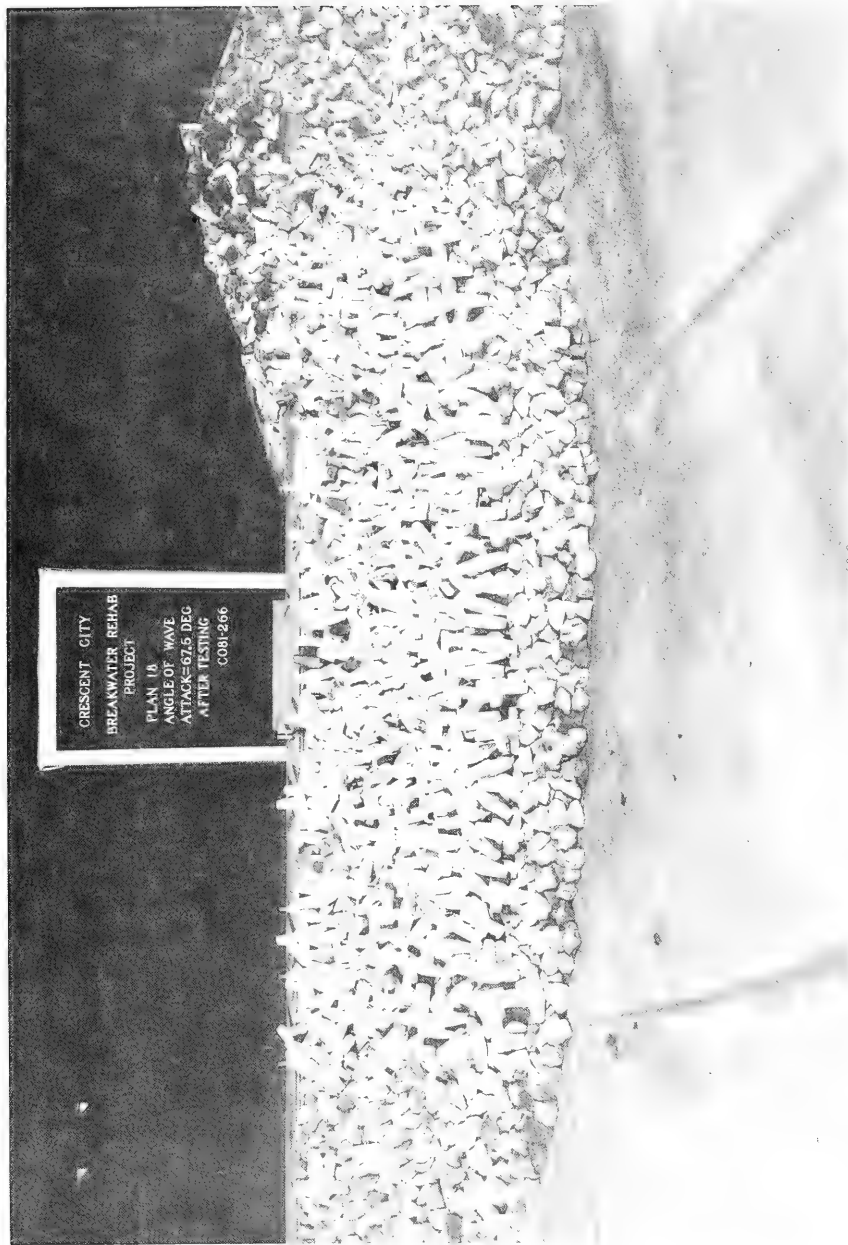


Photo 223. Sea-side view of Plan 18 after completion of Hydrograph A; 67.5-deg angle of wave attack



CORSON - CITY
BIOGRAPHIC RECORD
PLAN 18
ANGLE OF WAVE
ATTACHED TO
AFTER 1880
1880-1887

Photo 224. Seaward oblique view of Plan 18 after completion of Hydrograph A; 67.5-deg angle of wave attack

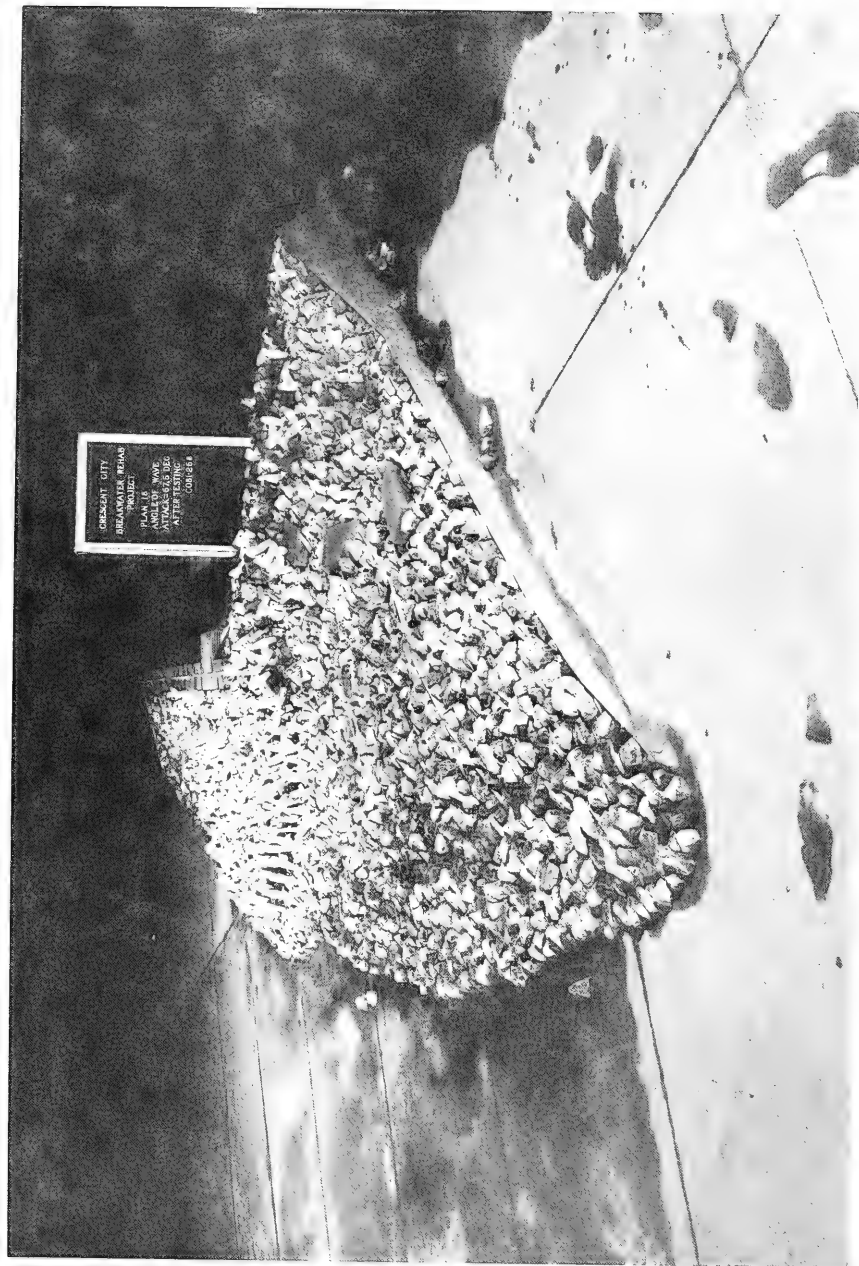


Photo 225. Seaward end view of Plan 18 after completion of Hydrograph A; 67.5-deg angle of wave attack

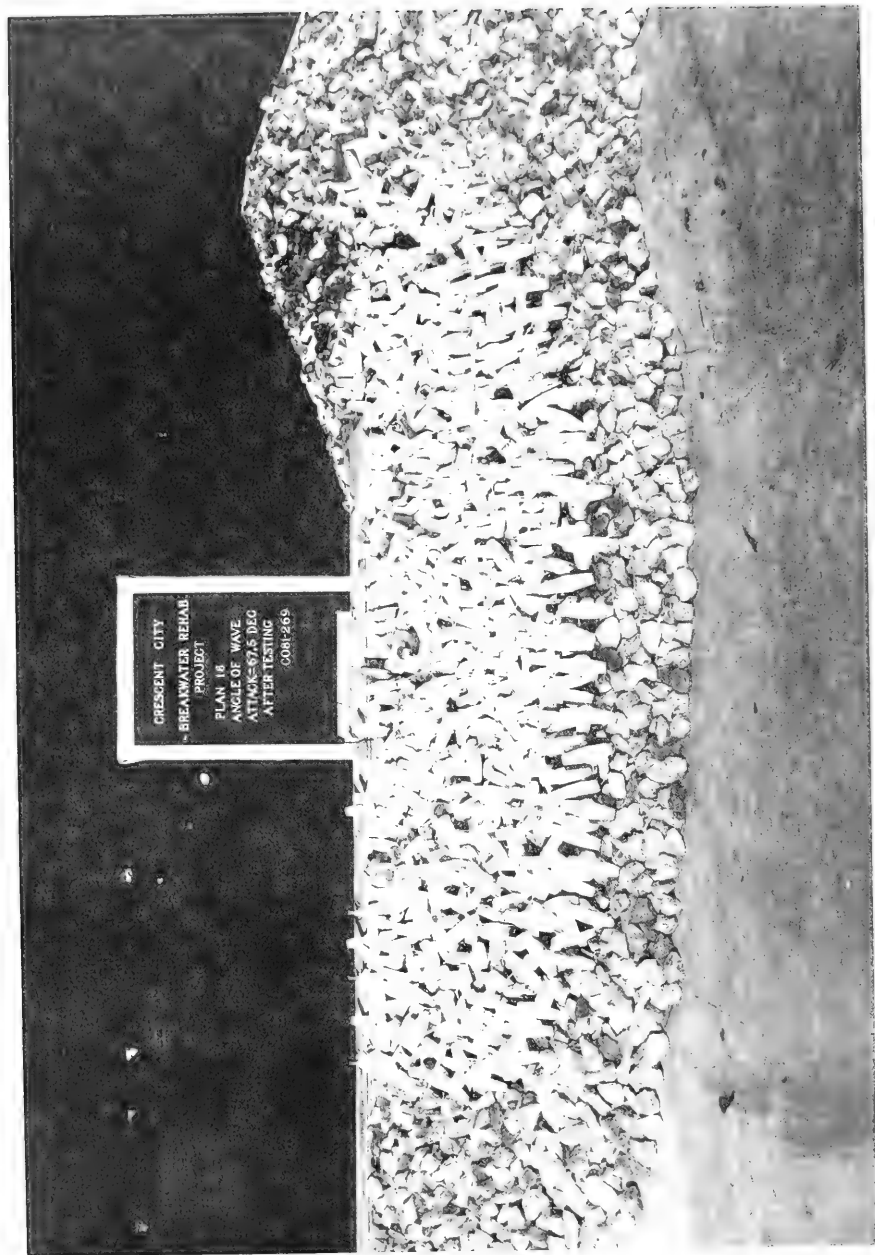


Photo 226. Sea-side view of Plan 18 after completion of Hydrograph B; 67.5-deg angle of wave attack

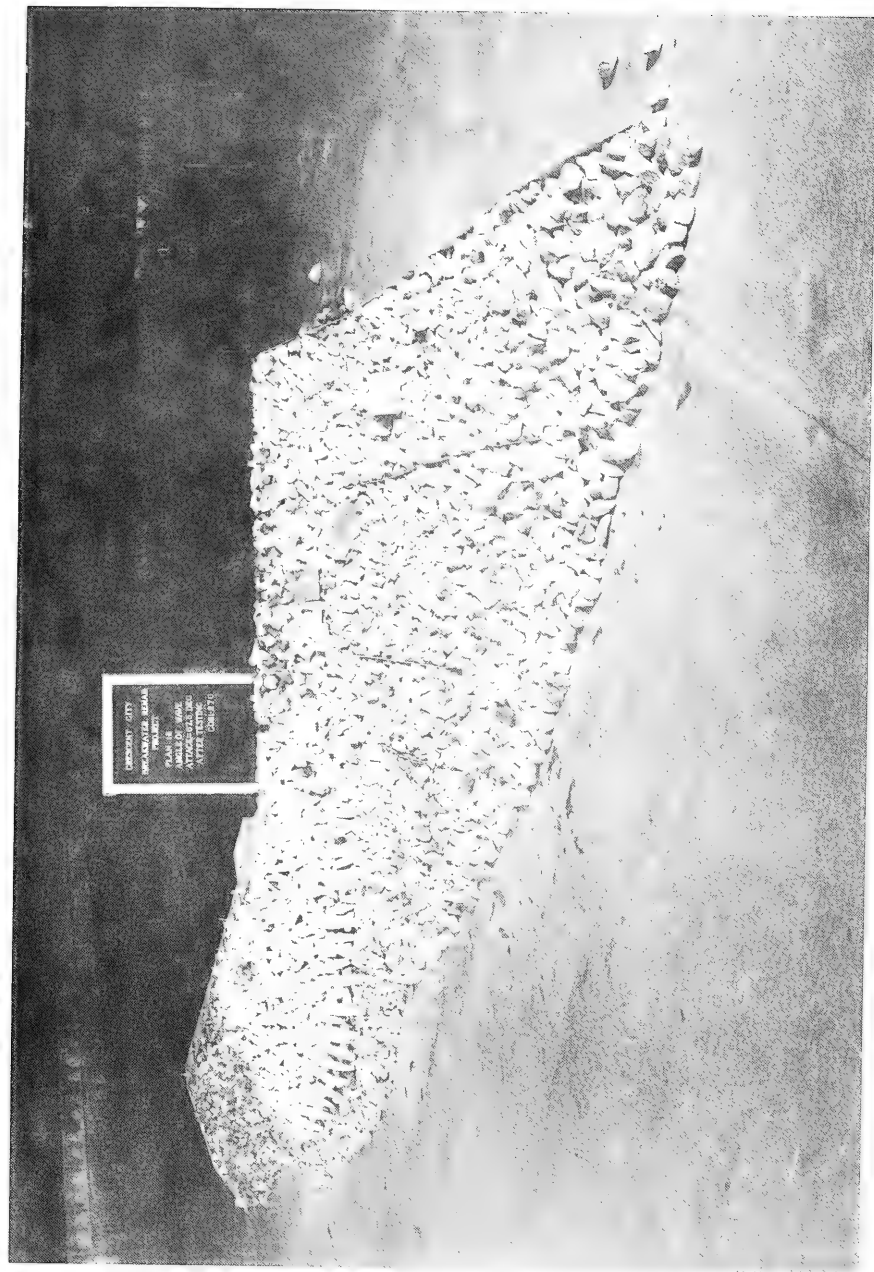


Photo 227. Seaward oblique view of Plan 18 after completion of Hydrograph B; 67.5-deg angle of wave attack

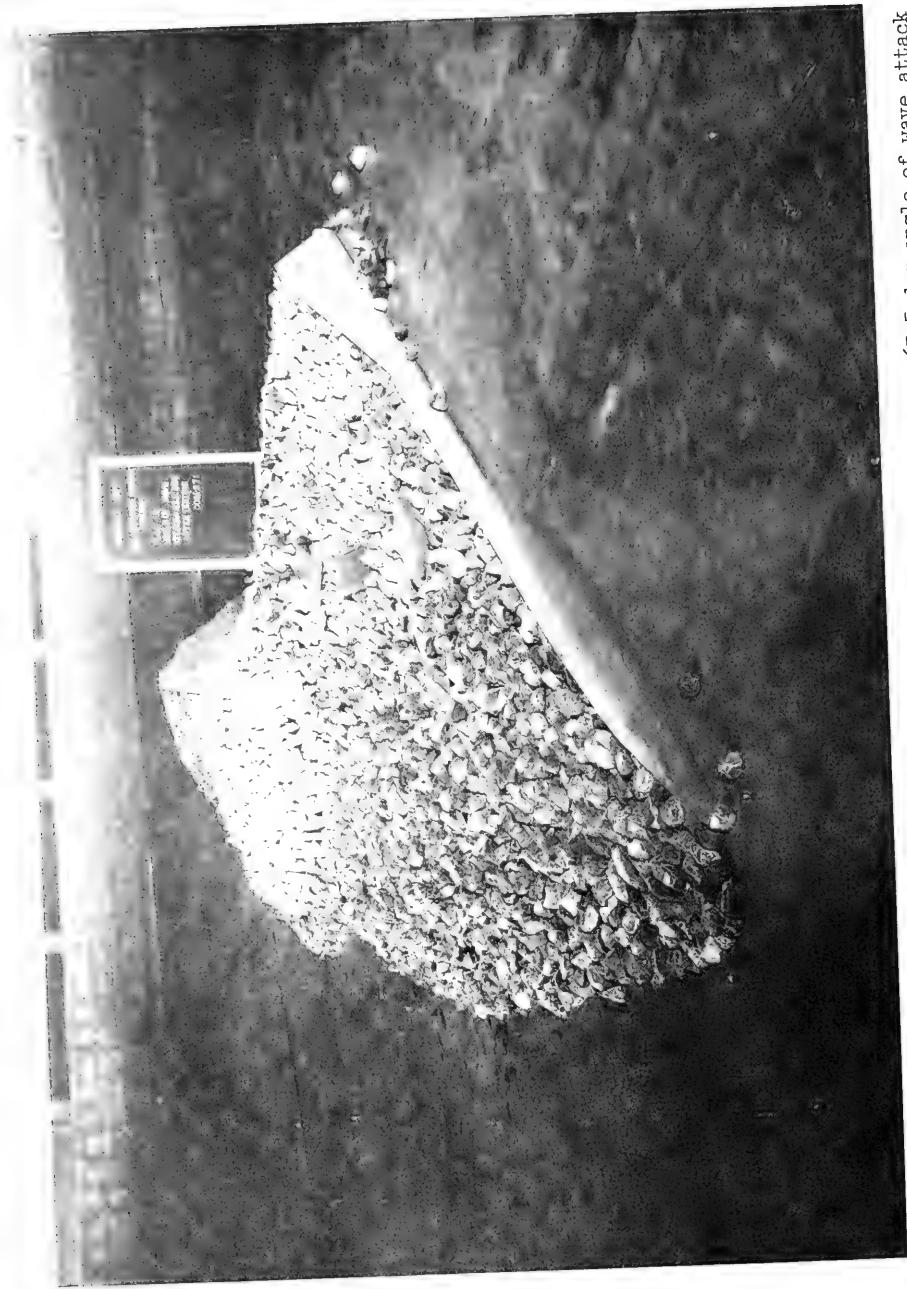


Photo 228. Seaward end view of Plan 18 after completion of Hydrograph B; 67.5-deg angle of wave attack

CRESCENT CITY
BREAKWATER REHAB
PROJECT
PLAN 26
ANGLE OF WAVE
ATTACK=67.6 DEG
BEFORE TESTING
C081-245



Photo 229. Sea-side view of Plan 26 before wave attack; 67.5-deg angle of wave attack



Photo 230. Seaward oblique view of Plan 26 before wave attack; 67.5-deg angle of wave attack



Photo 231. Seaward end view of Plan 26 before wave attack; 67.5-deg angle of wave attack

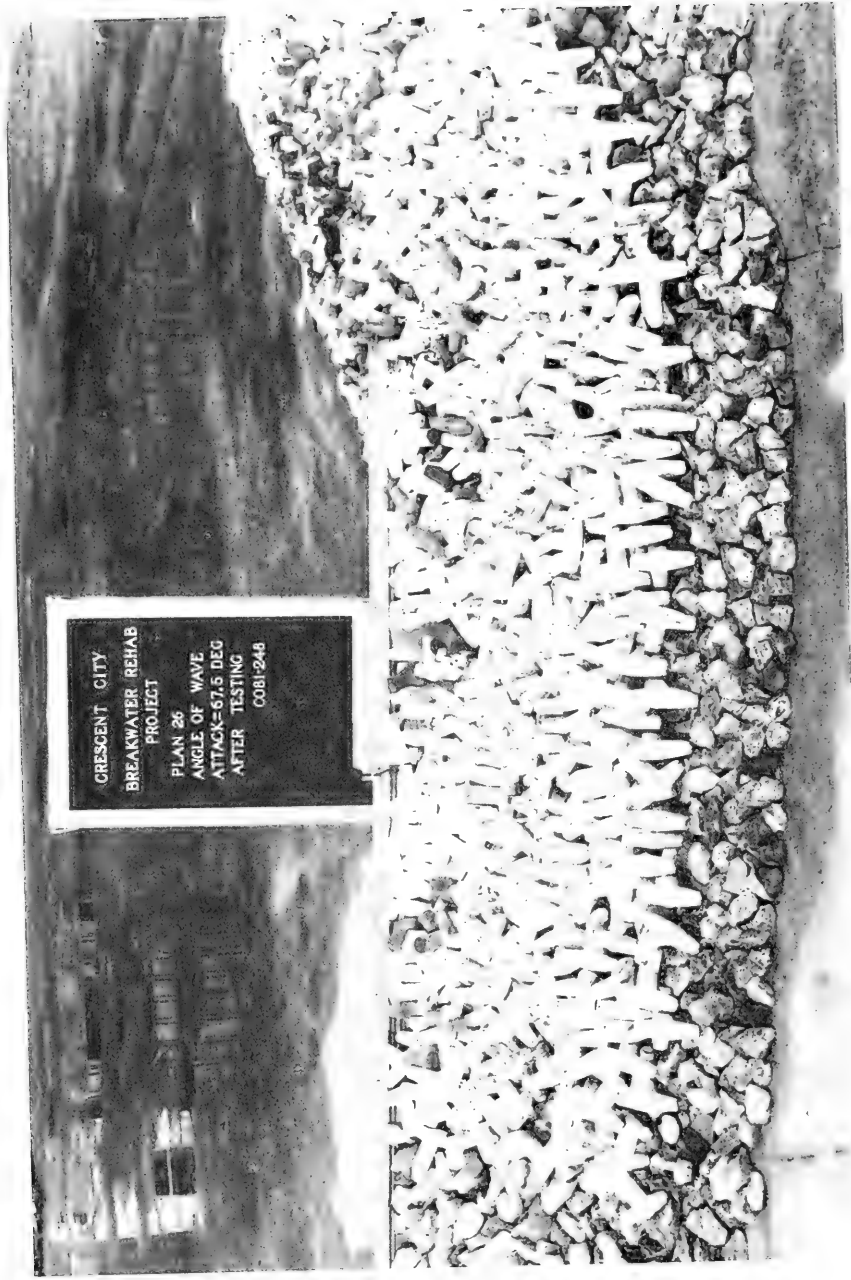


Photo 232. Sea-side view of Plan 26 after completion of abbreviated hydrograph; 67.5-deg angle of wave attack



Photo 233. Seaward oblique view of Plan 26 after completion of abbreviated hydrograph; 67.5-deg angle of wave attack



Photo 234. Seaward end view of Plan 26 after completion of abbreviated hydrograph; 67.5-deg angle of wave attack

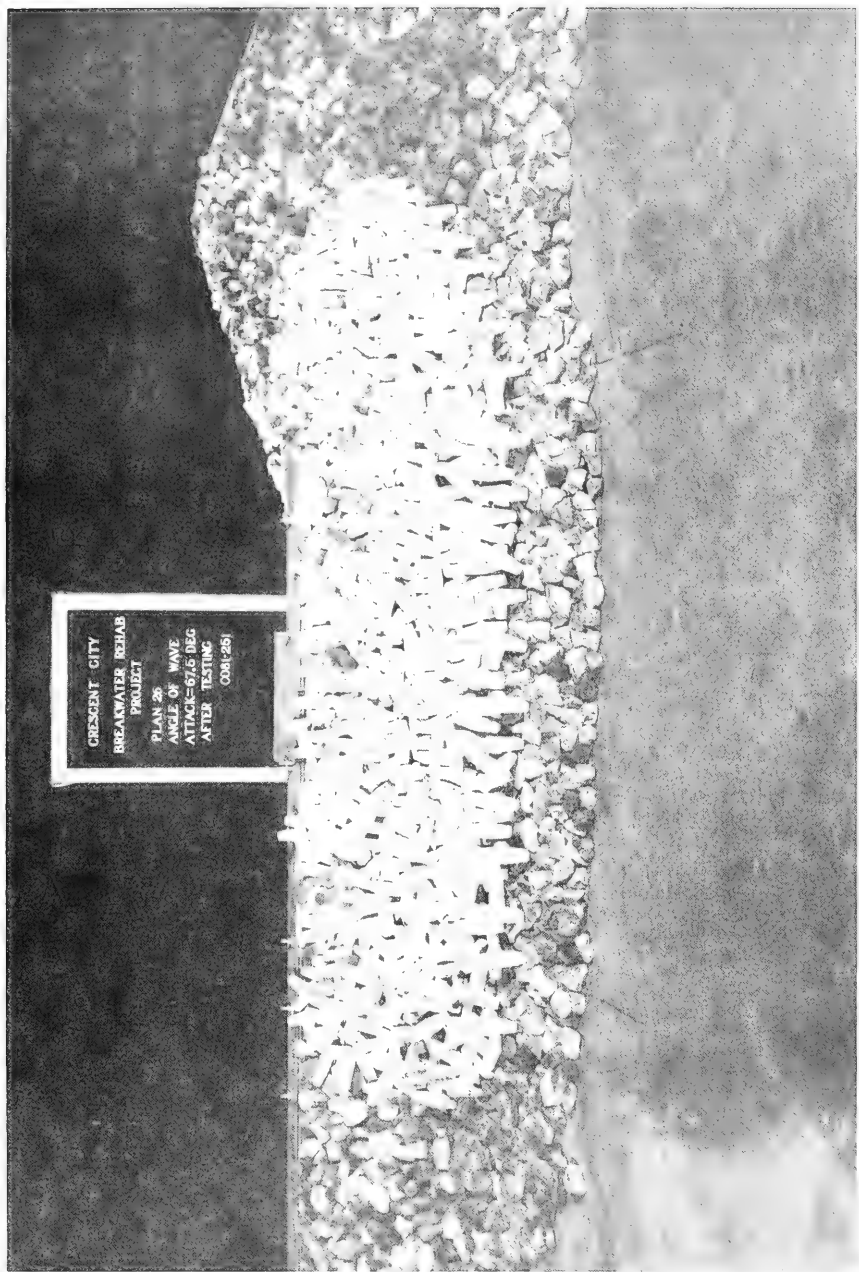


Photo 235. Sea-side view of Plan 26 repeat after completion of abbreviated hydrograph; 67.5-deg angle of wave attack



Photo 236. Seaward oblique view of Plan 26 repeat after completion of abbreviated hydrograph; 67.5-deg angle of wave attack

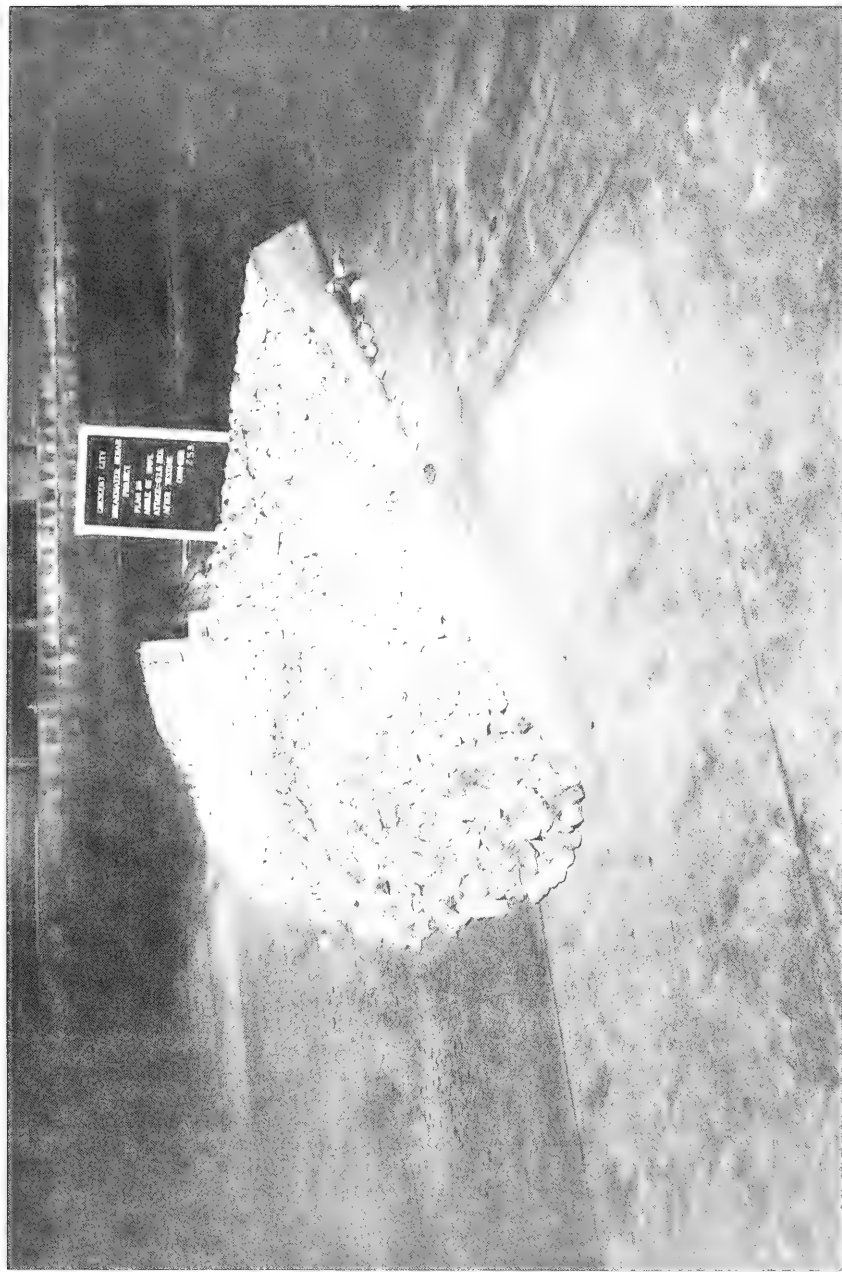


Photo 237. Seaward end view of Plan 26 repeat after completion of abbreviated hydrograph; 67.5-deg angle of wave attack

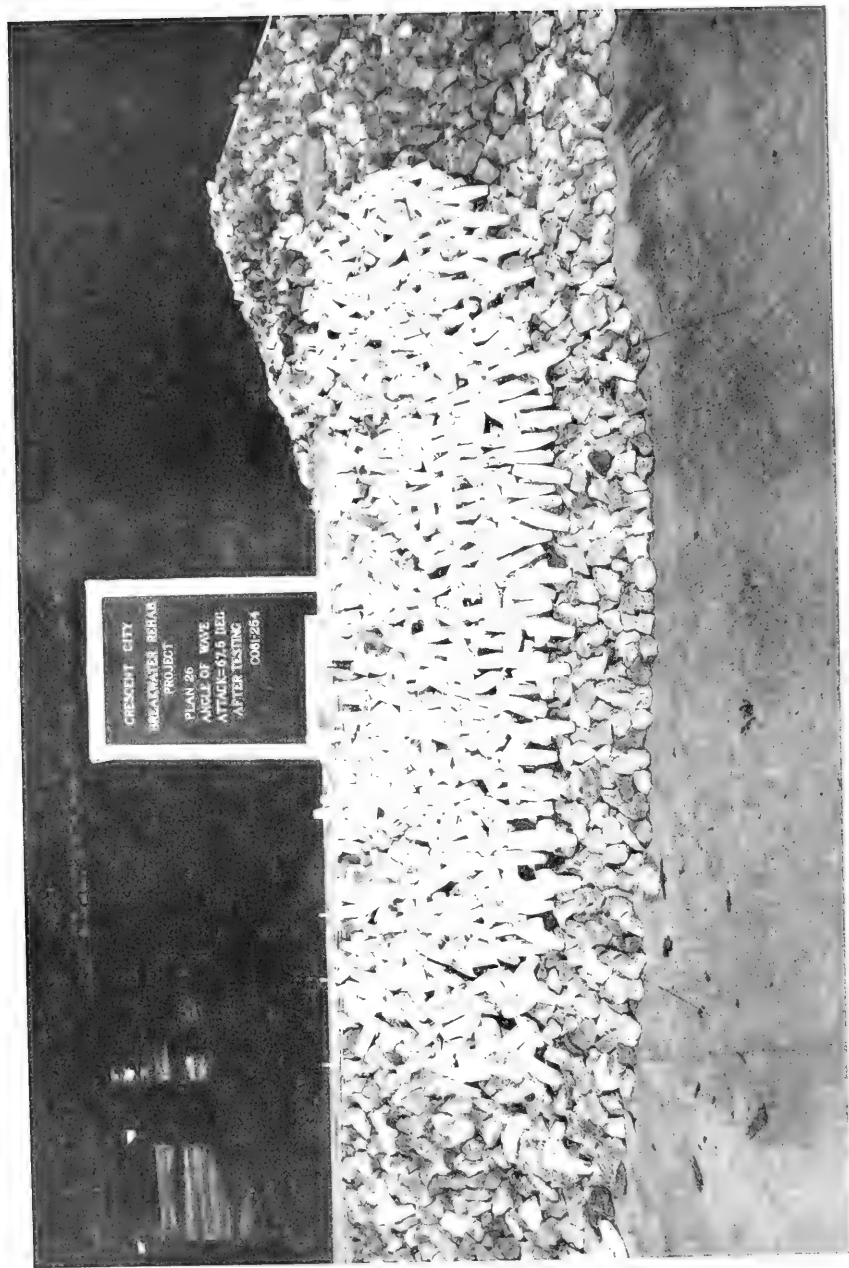


Photo 238. Sea-side view of Plan 26 after completion of Hydrograph A; 67.5-deg angle of wave attack

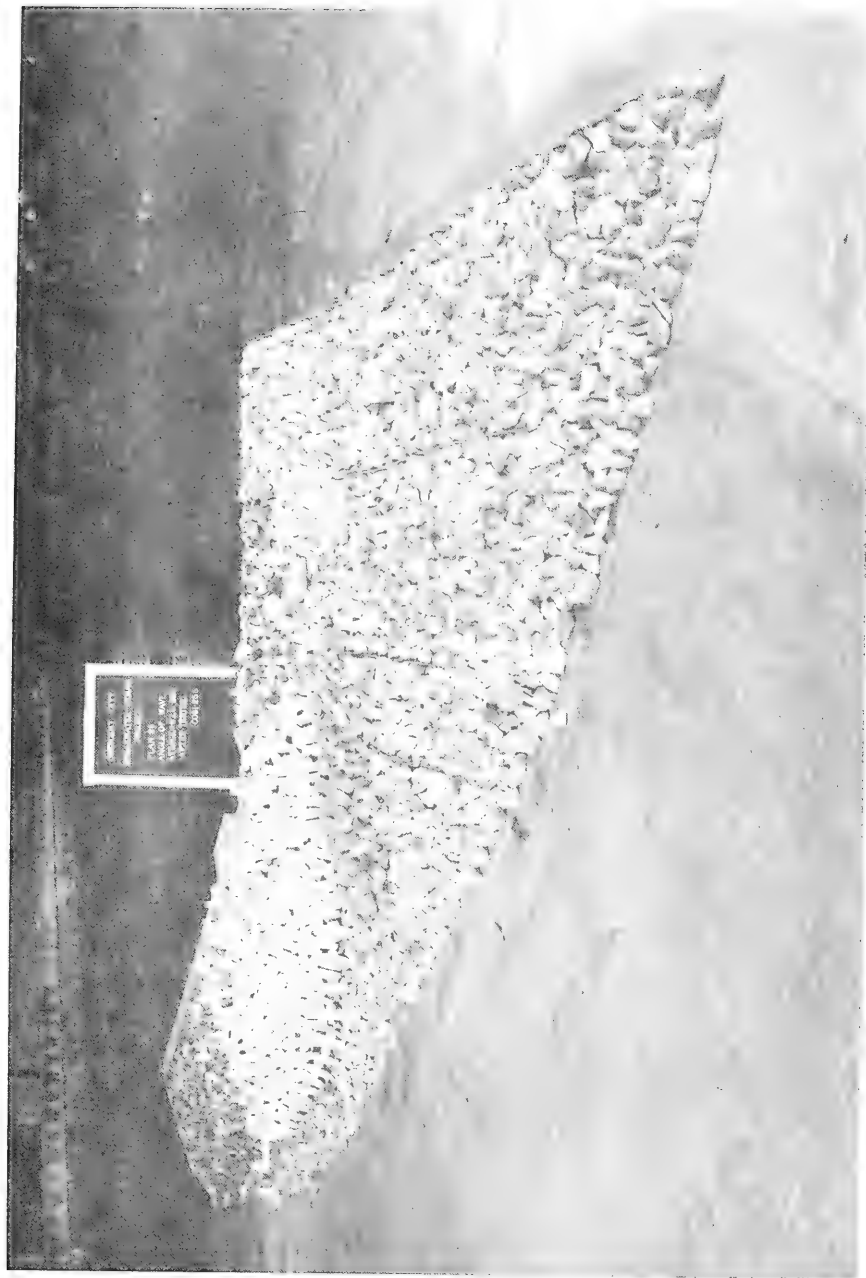


Photo 239. Seaward oblique view of Plan 26 after completion of Hydrograph A; 67.5-deg angle of wave attack

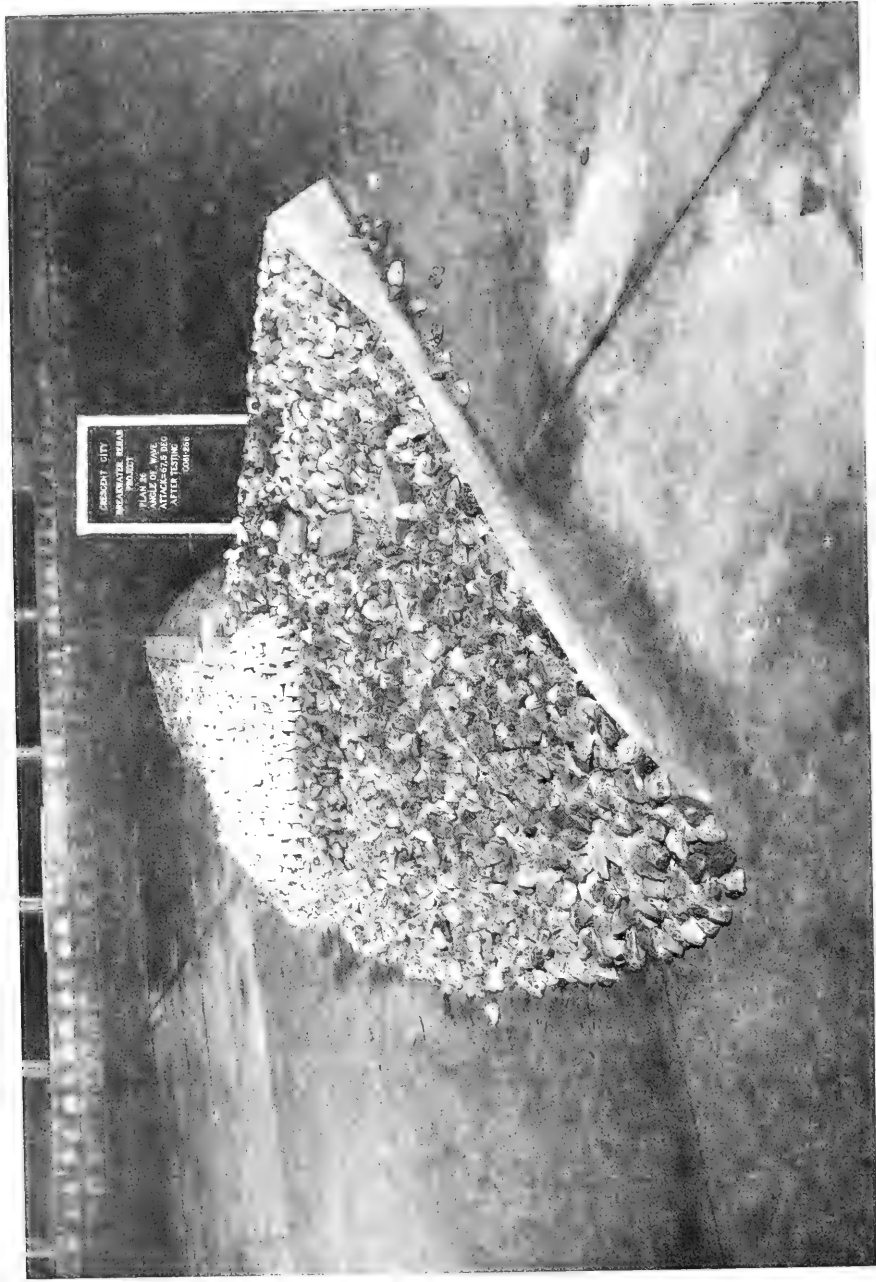


Photo 240. Seaward end view of Plan 26 after completion of Hydrograph A; 67.5-deg angle of wave attack

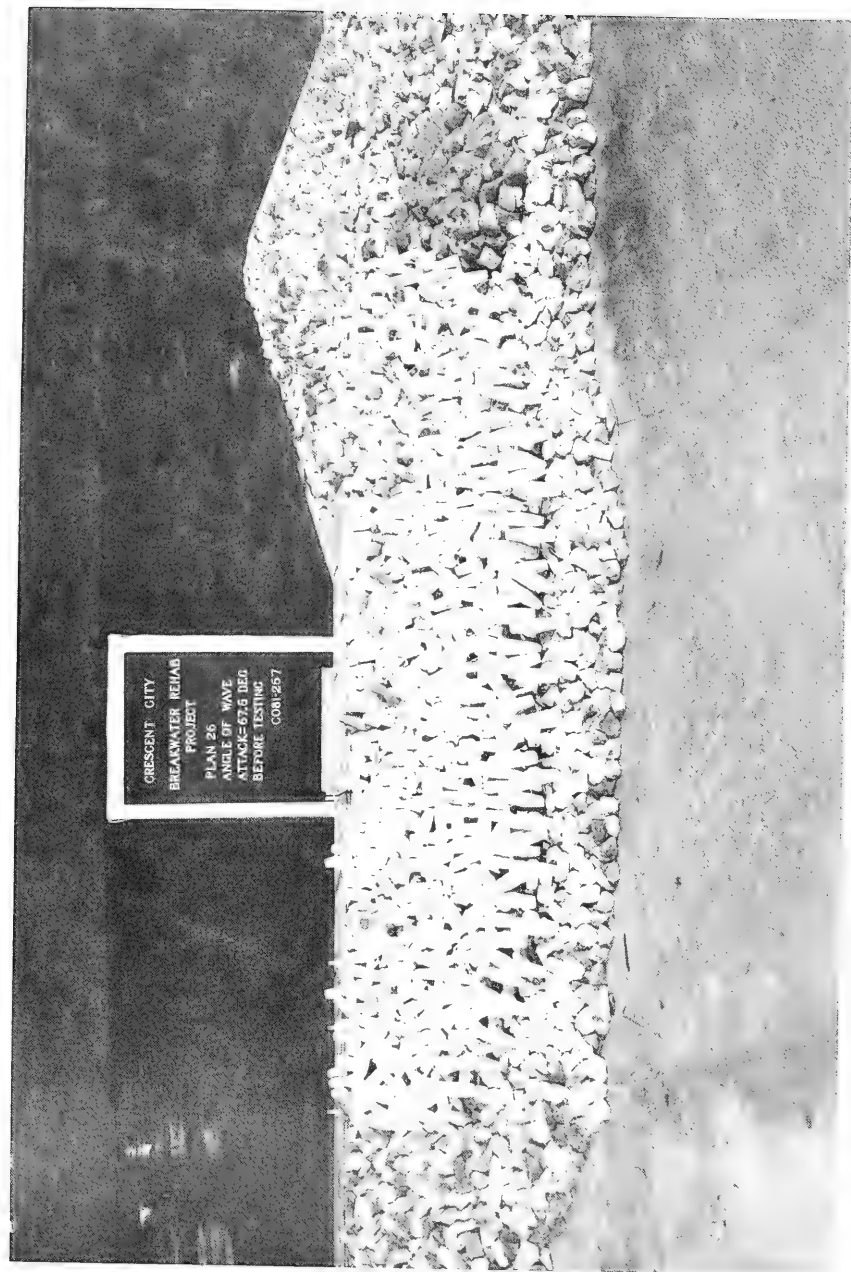


Photo 241. Sea-side view of Plan 26 before wave attack after modification to shoreward transition; 67.5-deg angle of wave attack

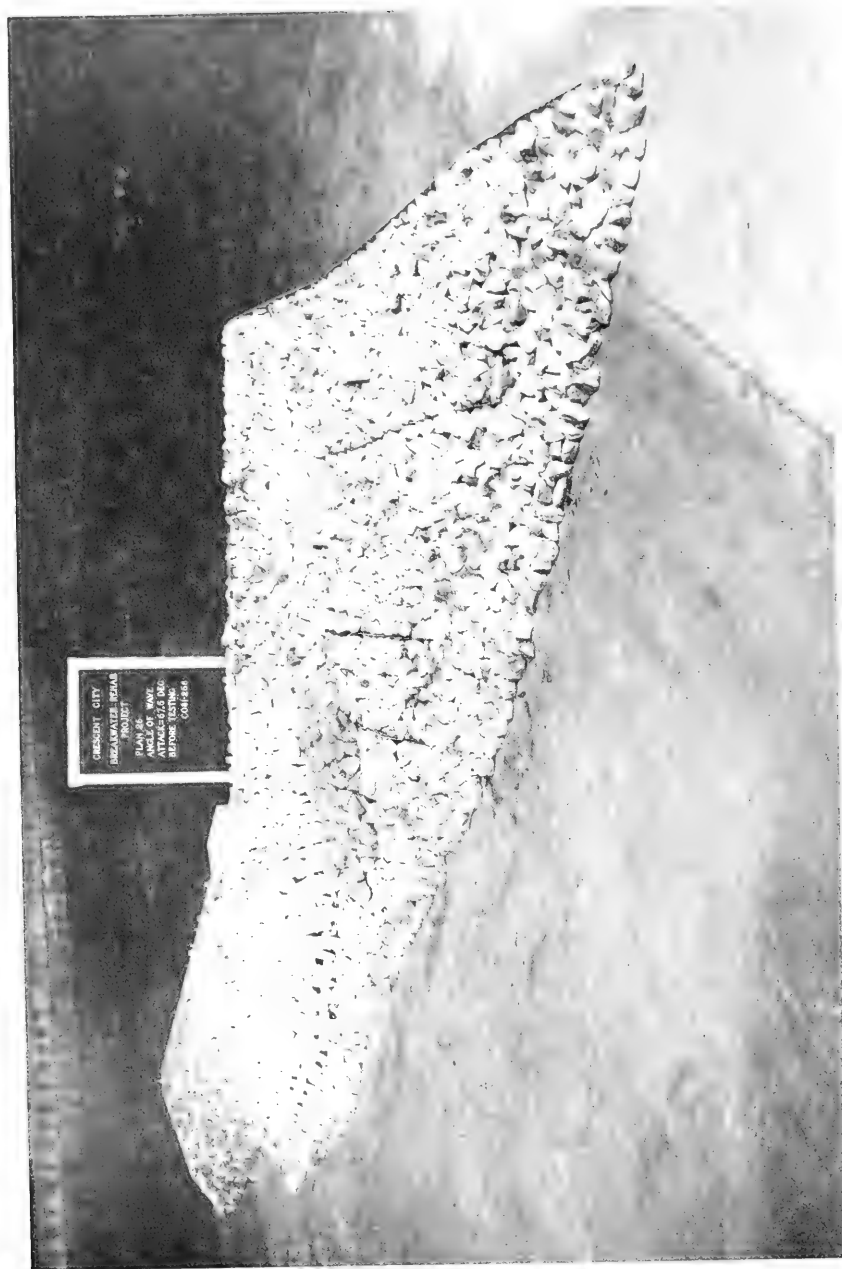


Photo 242. Seaward oblique view of Plan 26 before wave attack after modification to shoreward transition; 67.5-deg angle of wave attack



Photo 243. Seaward end view of Plan 26 before wave attack after modification to shoreward transition; 67.5-deg angle of wave attack

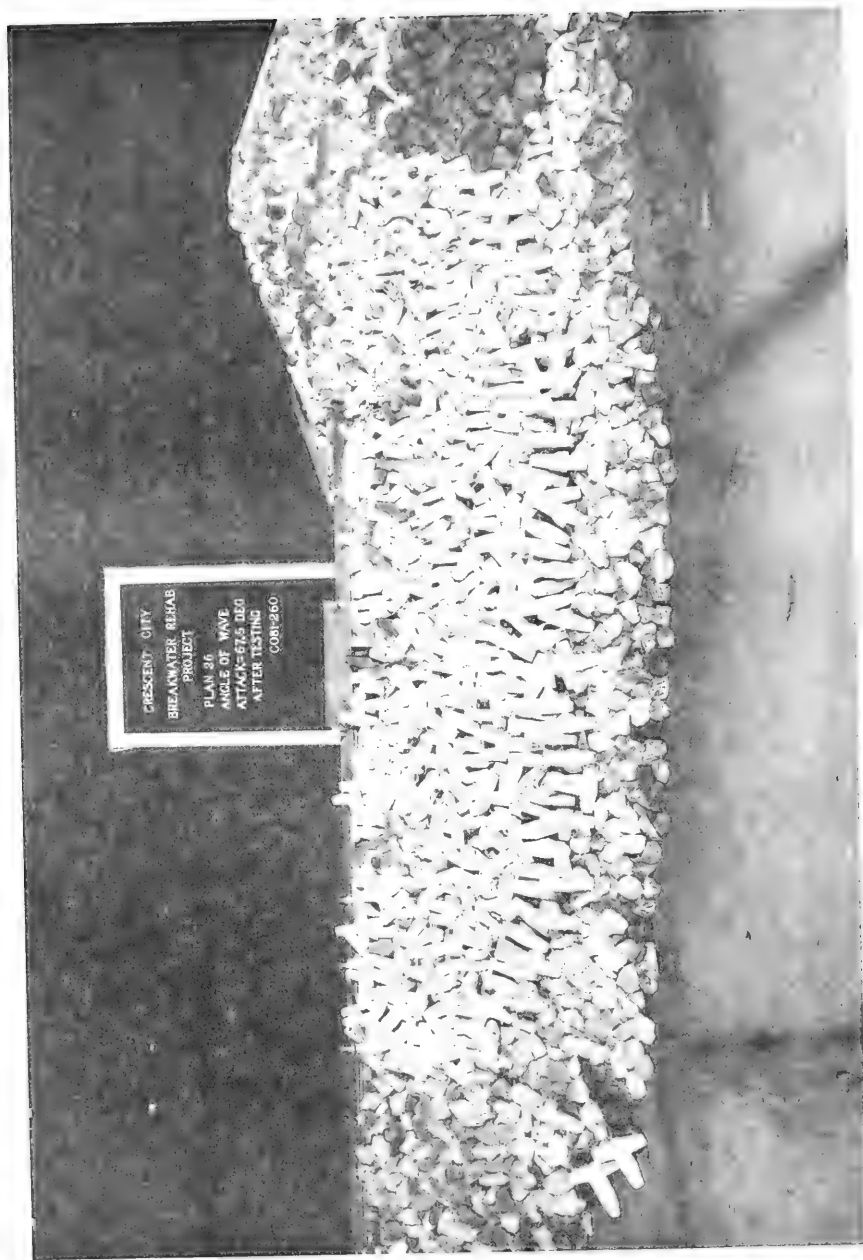


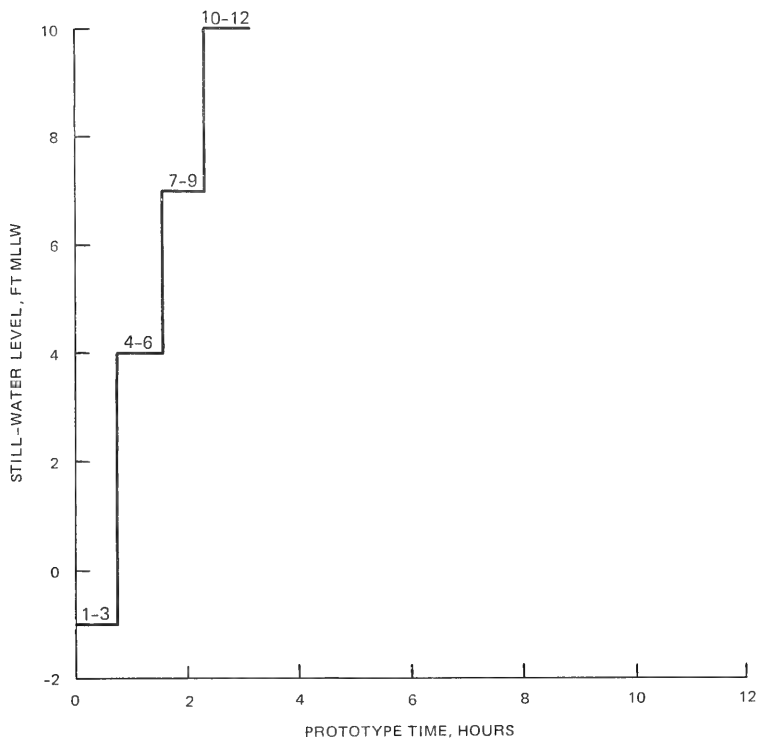
Photo 244. Sea-side view of Plan 26 after completion of Hydrograph B; 67.5-deg angle of wave attack



Photo 245. Seaward oblique view of Plan 26 after completion of Hydrograph B; 67.5-deg angle of wave attack

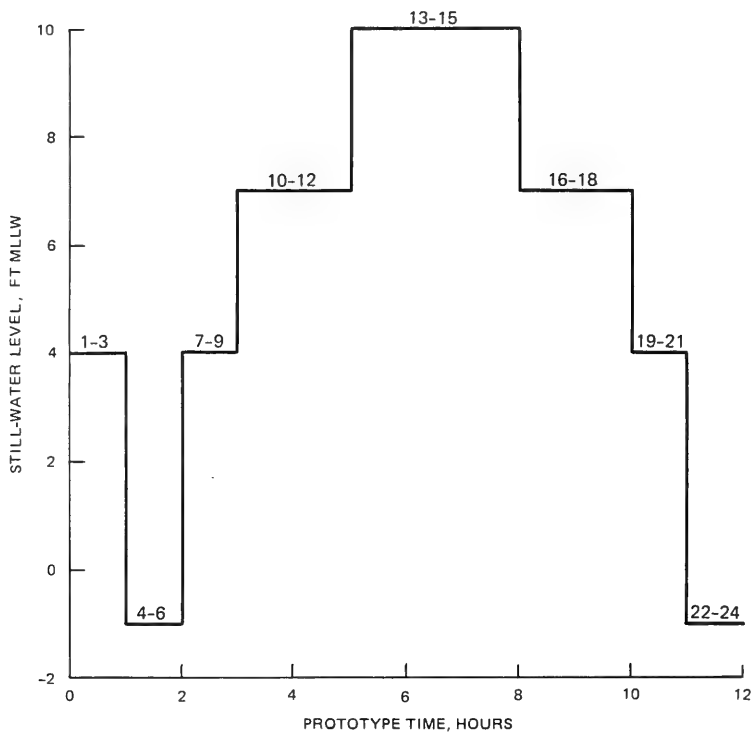


photo 246. Seaward end view of Plan 26 after completion of Hydrograph B; 67.5-deg angle of wave attack



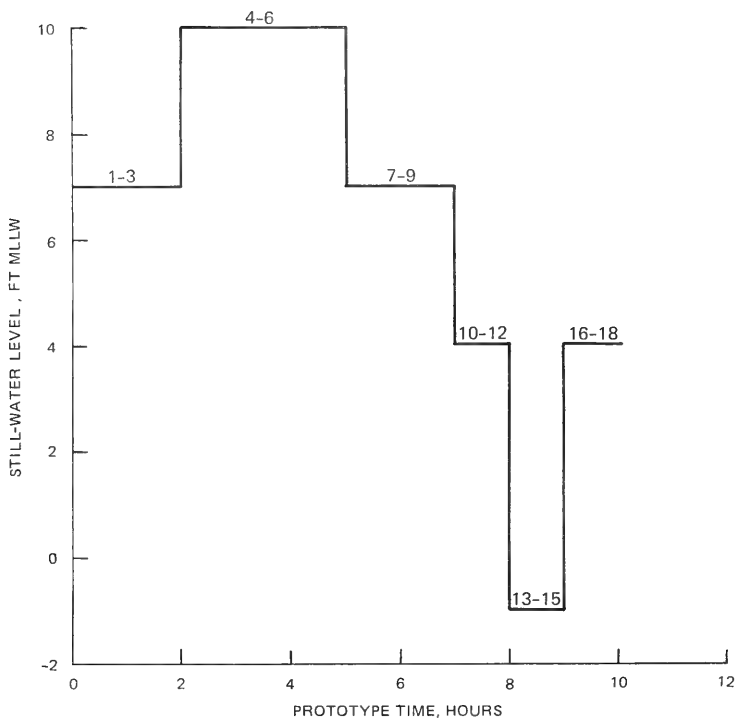
NOTES: NUMBERS INDICATE HYDROGRAPH
STEP NUMBER
TEST CONDITIONS FOR EACH STEP
ARE GIVEN IN TABLE 1

ABBREVIATED
HYDROGRAPH



NOTES: NUMBERS INDICATE HYDROGRAPH
STEP NUMBER.
TEST CONDITIONS FOR EACH
STEP ARE GIVEN IN TABLE 2.

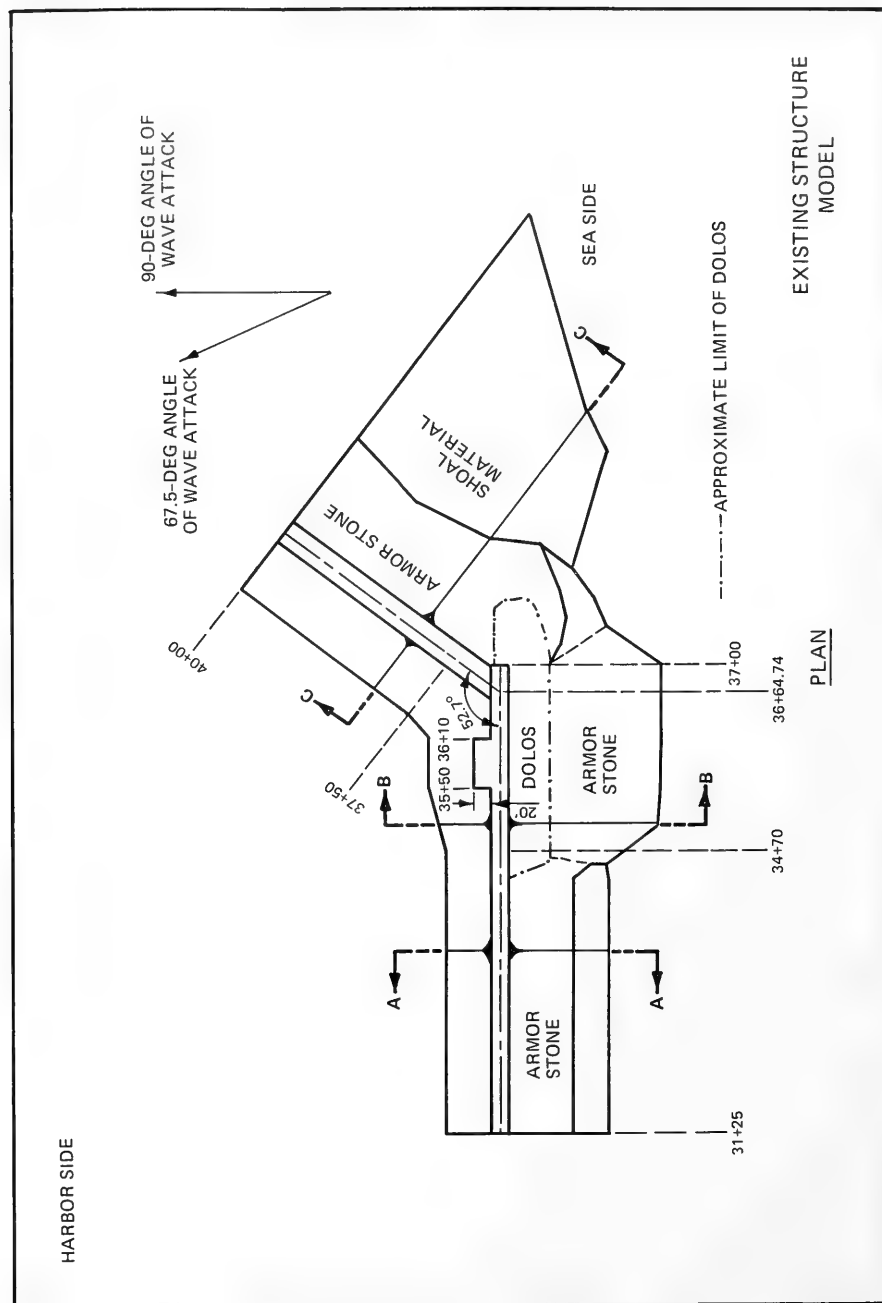
HYDROGRAPH A

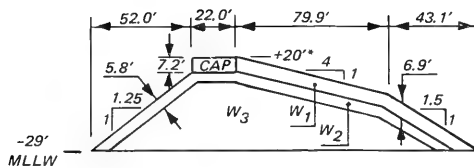


NOTES: NUMBERS INDICATE HYDROGRAPH
STEP NUMBER.

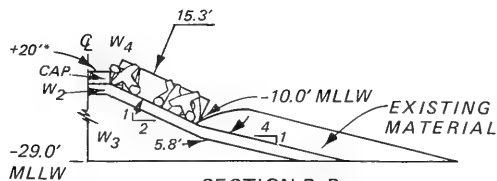
TEST CONDITIONS FOR EACH
STEP ARE GIVEN IN TABLE 3.

HYDROGRAPH B

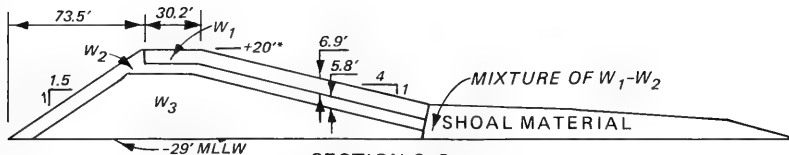




SECTION A-A



SECTION B-B



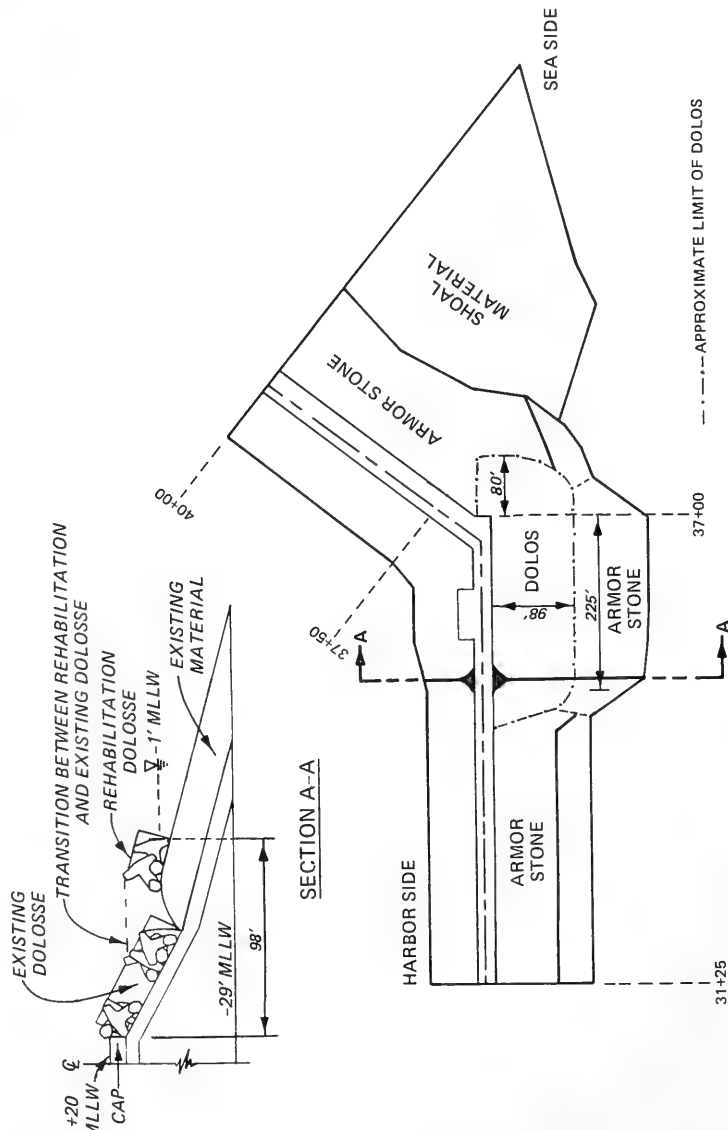
SECTION C-C

MATERIAL CHARACTERISTICS

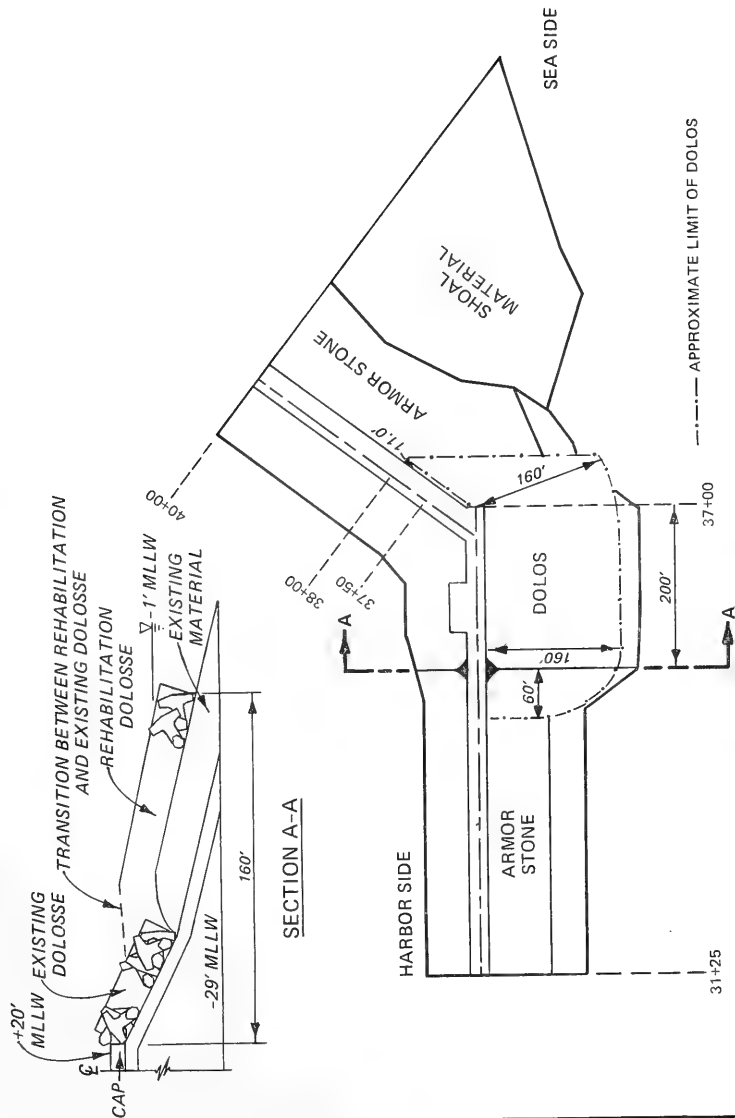
MODEL	PROTOTYPE
** W ₁ = 0.28 LB STONE @ 165 PCF	W ₁ = 25 TON STONE @ 170 PCF
** W ₂ = 0.13 LB STONE @ 165 PCF	W ₂ = 12 TON STONE @ 170 PCF
W ₃ = 0.005 TO 0.025 LB STONE @ 165 PCF	W ₃ = 0.45 TO 2.25 TON STONE @ 170 PCF
*** W ₄ = 0.59 LB DOLOS @ 141 PCF	W ₄ = 42 TON DOLOS @ 156 PCF

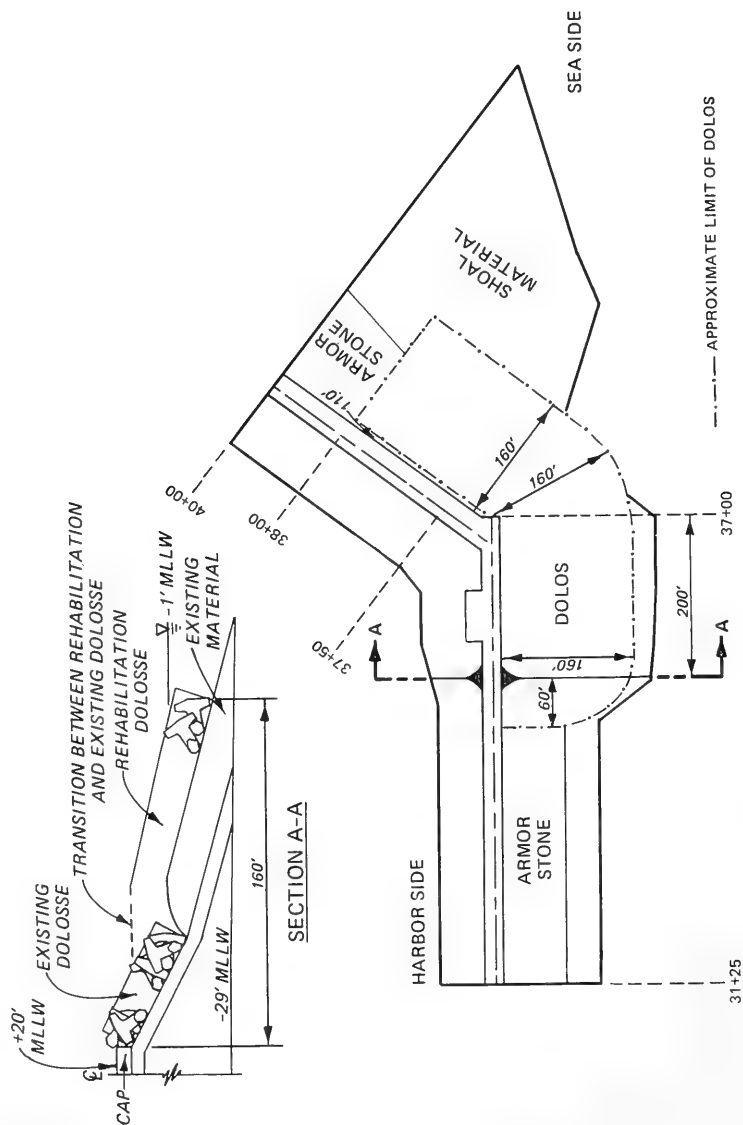
* ELEVATIONS IN FEET REFER TO MLLW
 ** RANDOM PLACED ARMOR STONE
 *** TWO LAYERS; RANDOM PLACED

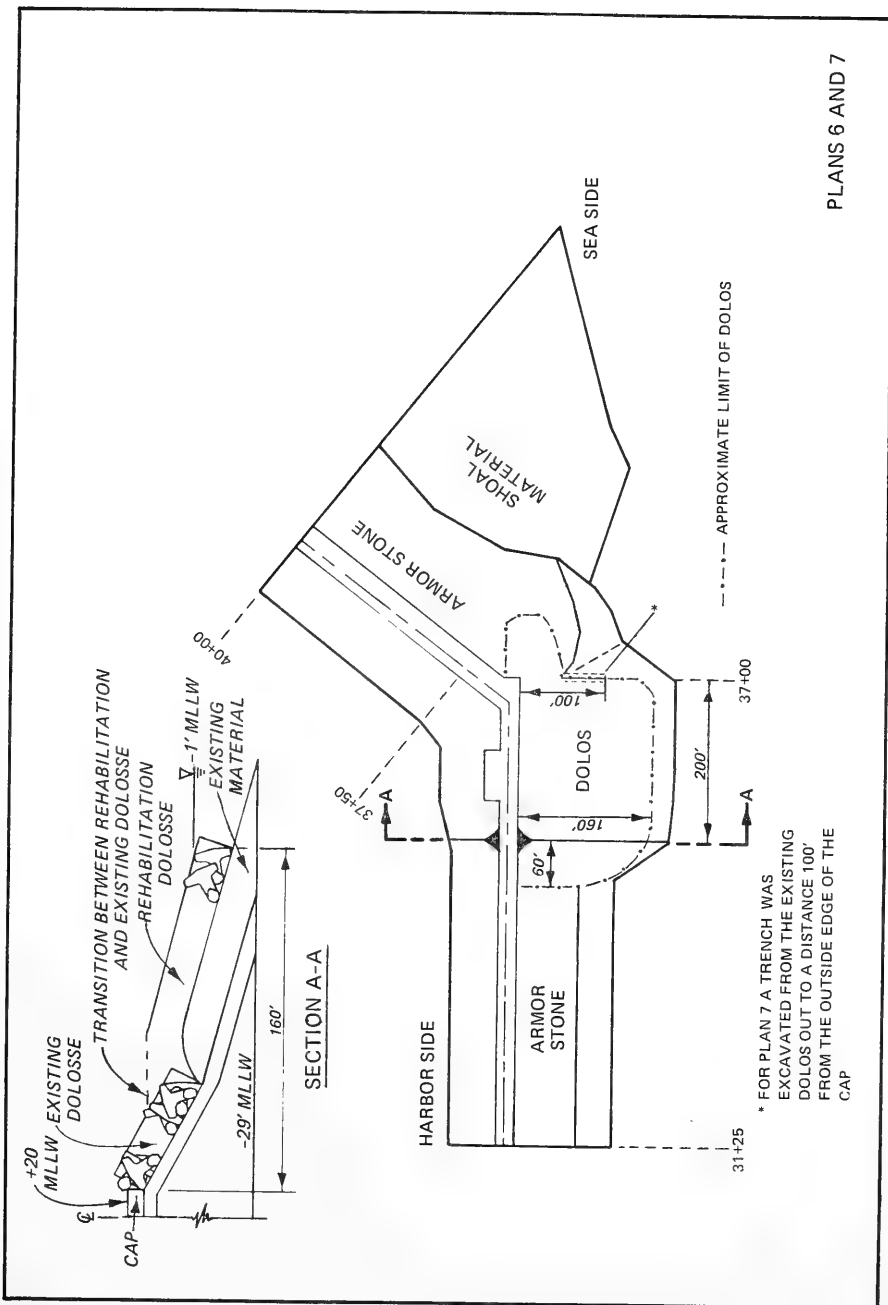
CROSS-SECTIONS FROM
 EXISTING STRUCTURE-MODEL



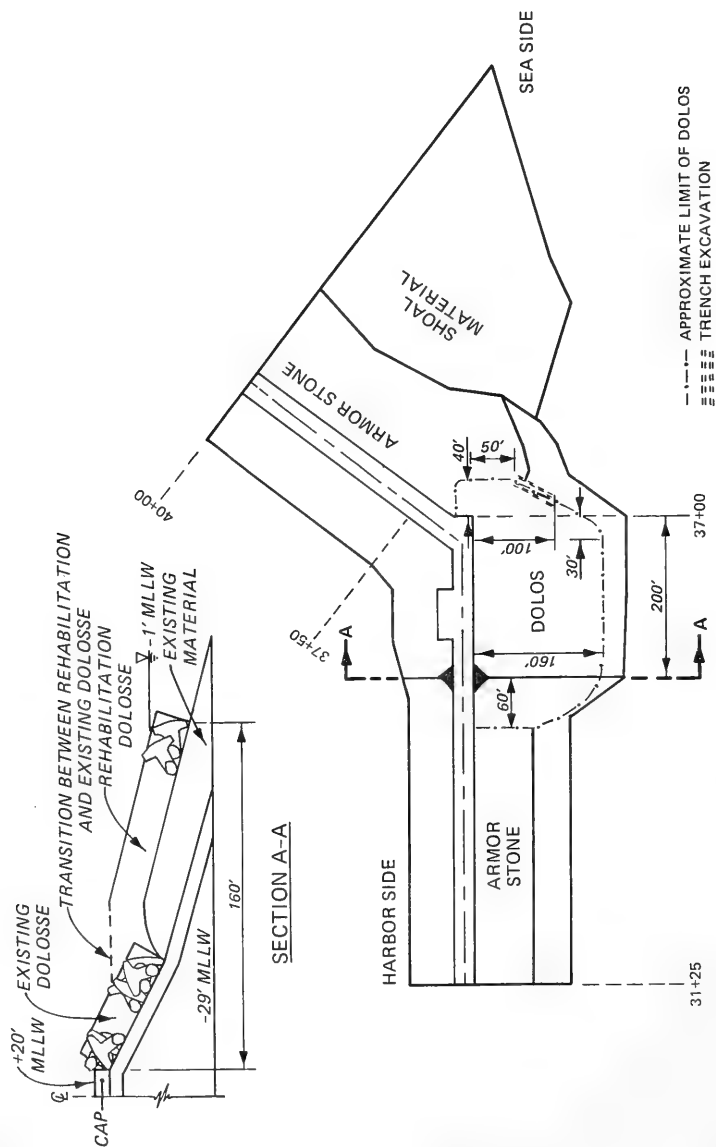


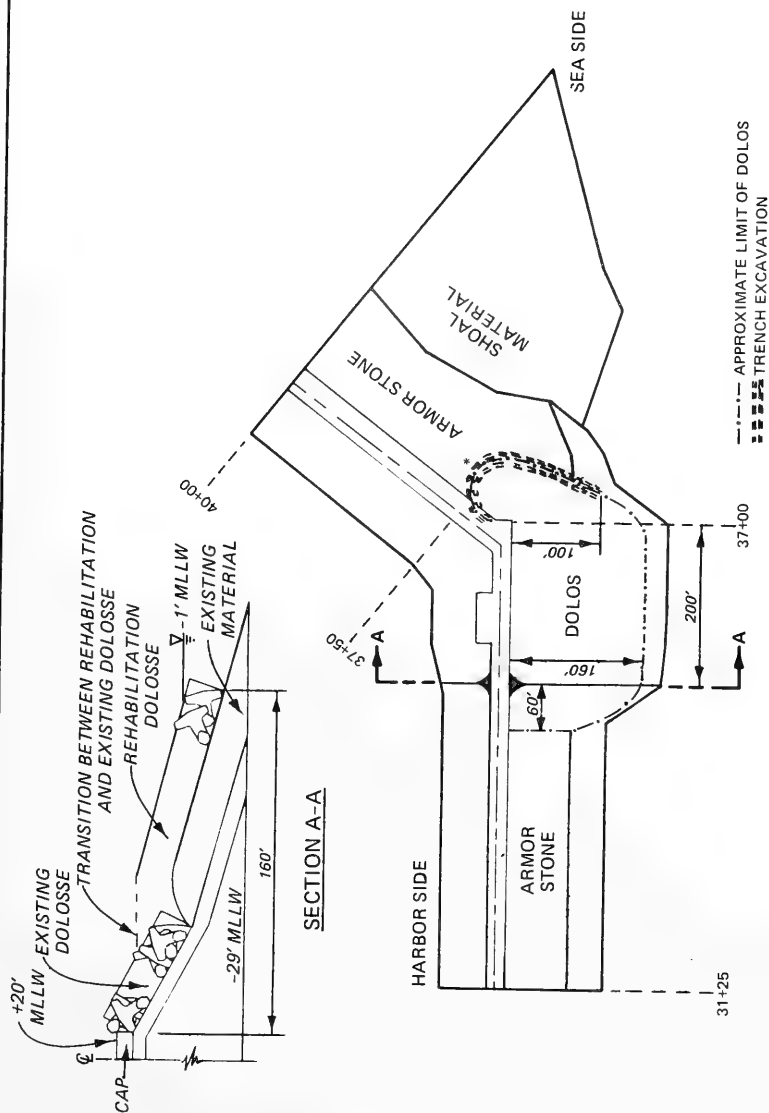




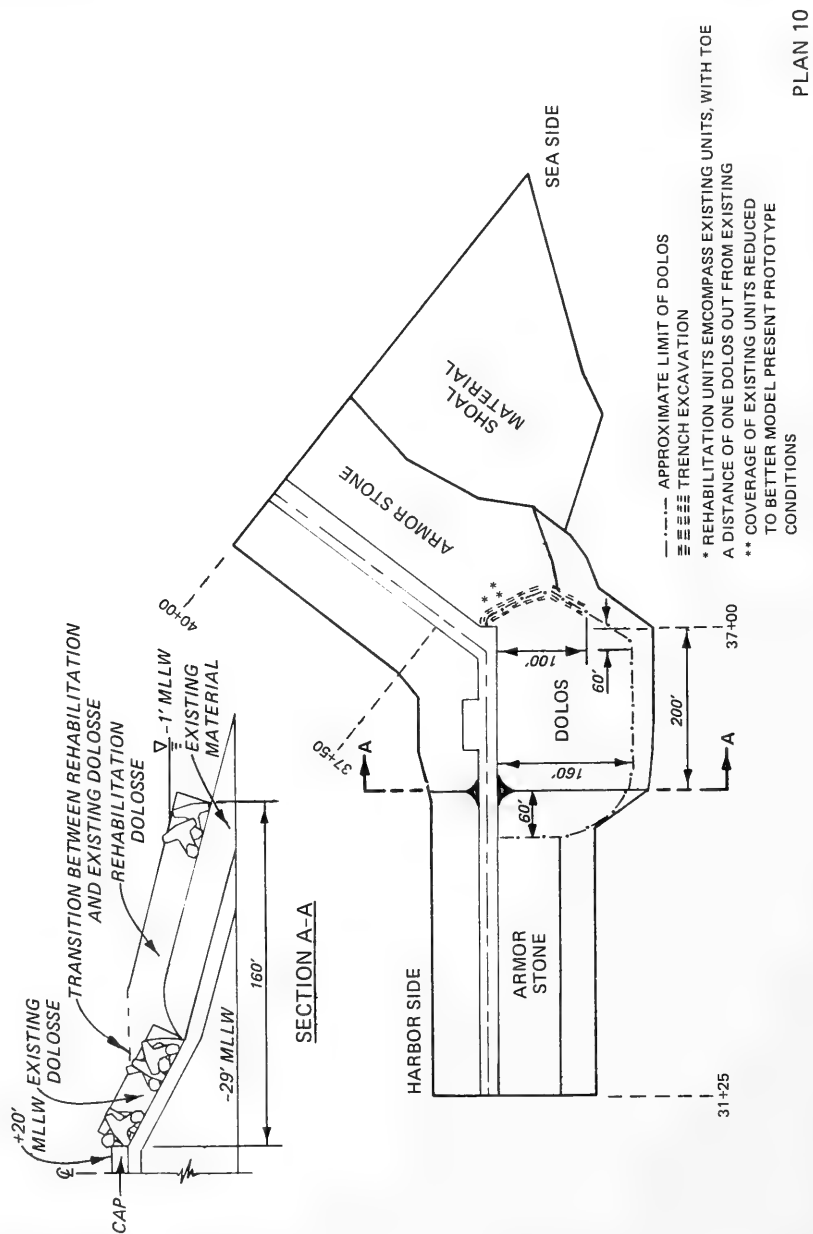


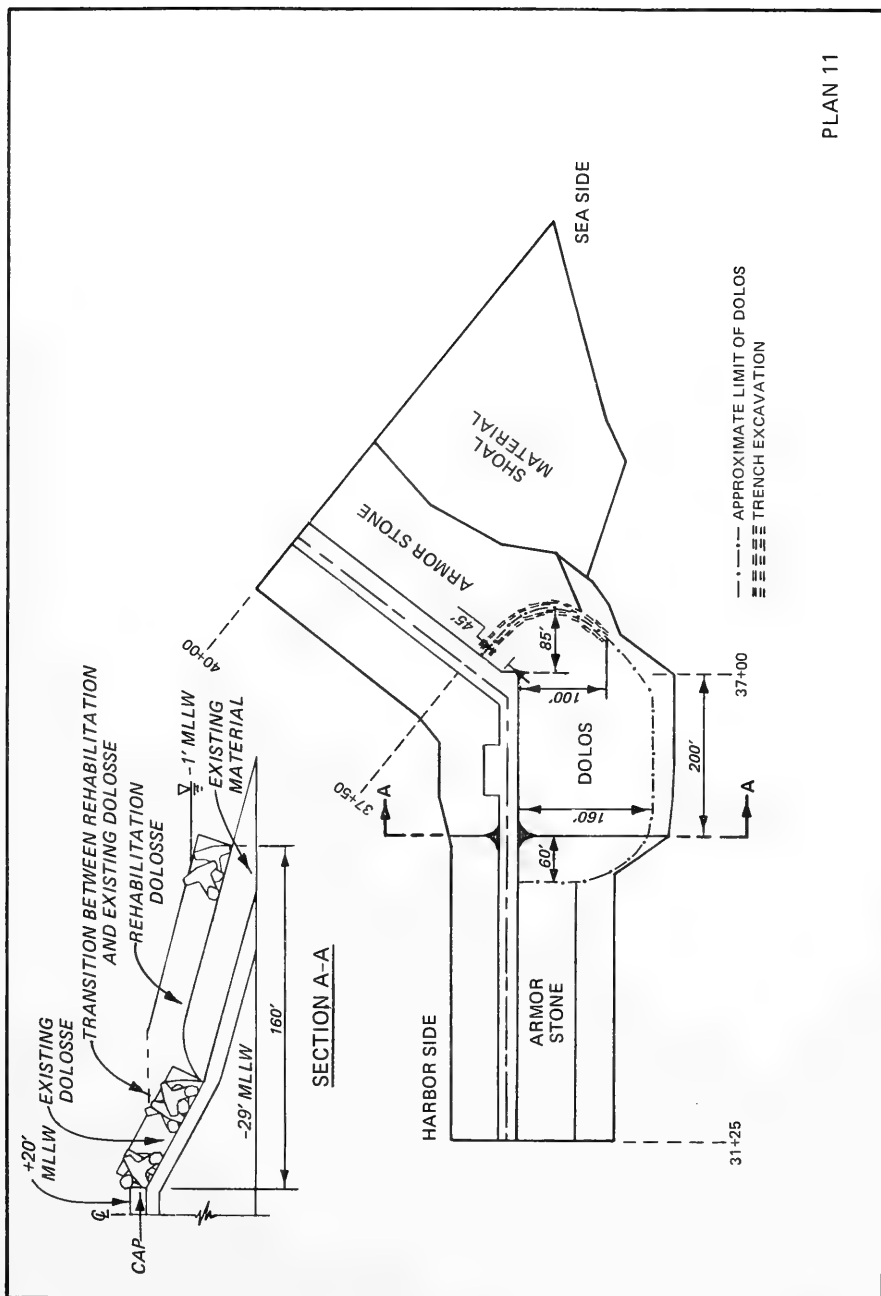
PLANS 6 AND 7



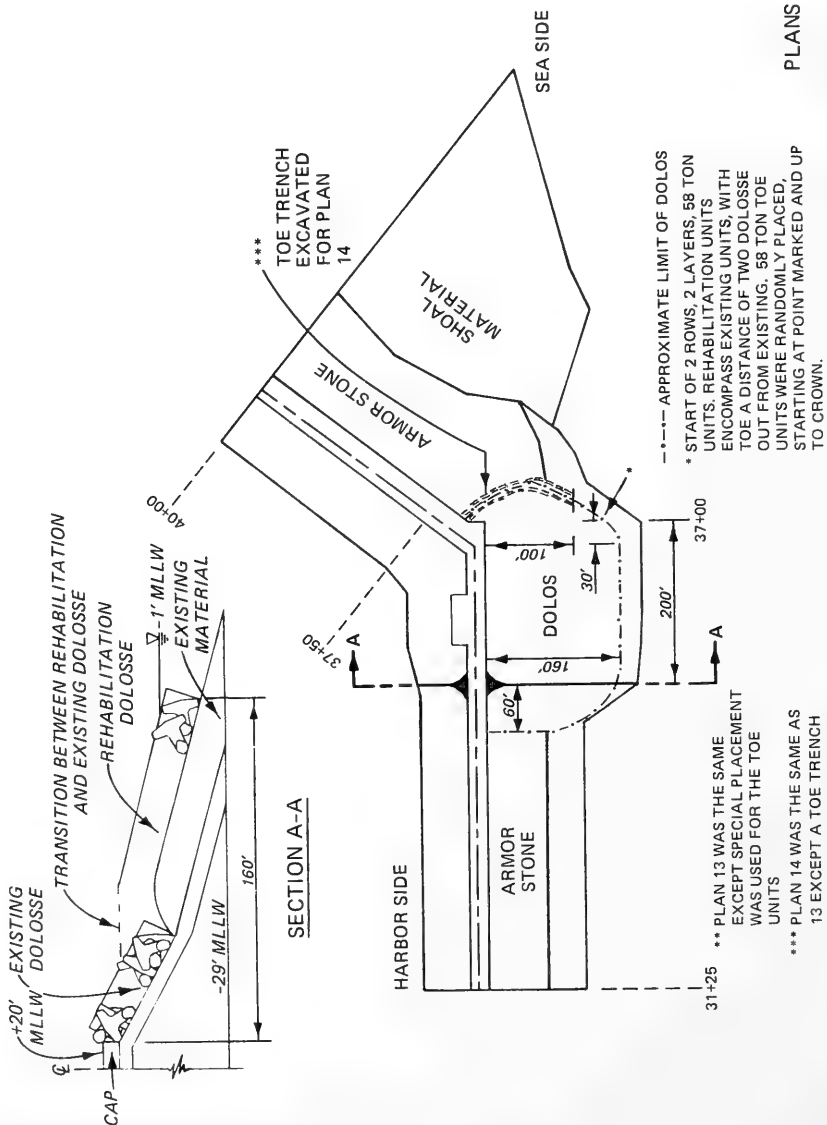


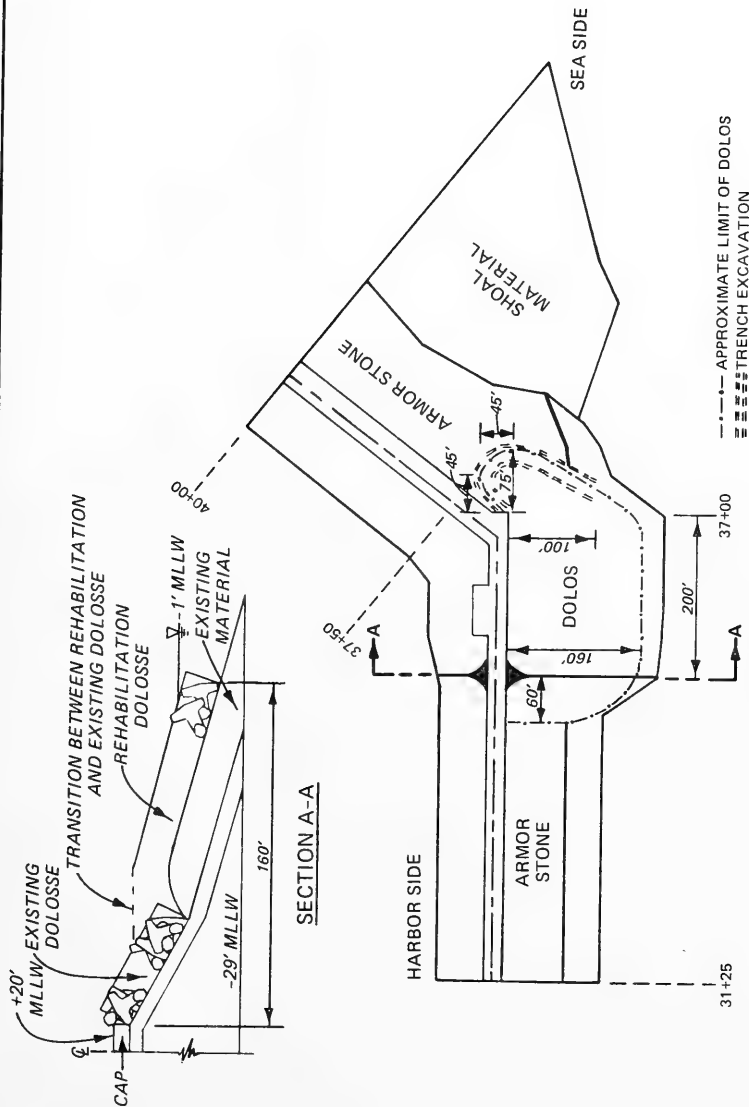
* REHABILITATION UNITS EMCOMPASS EXISTING UNITS, WITH TOE A DISTANCE OF ONE DOLOSSE OUT FROM EXISTING

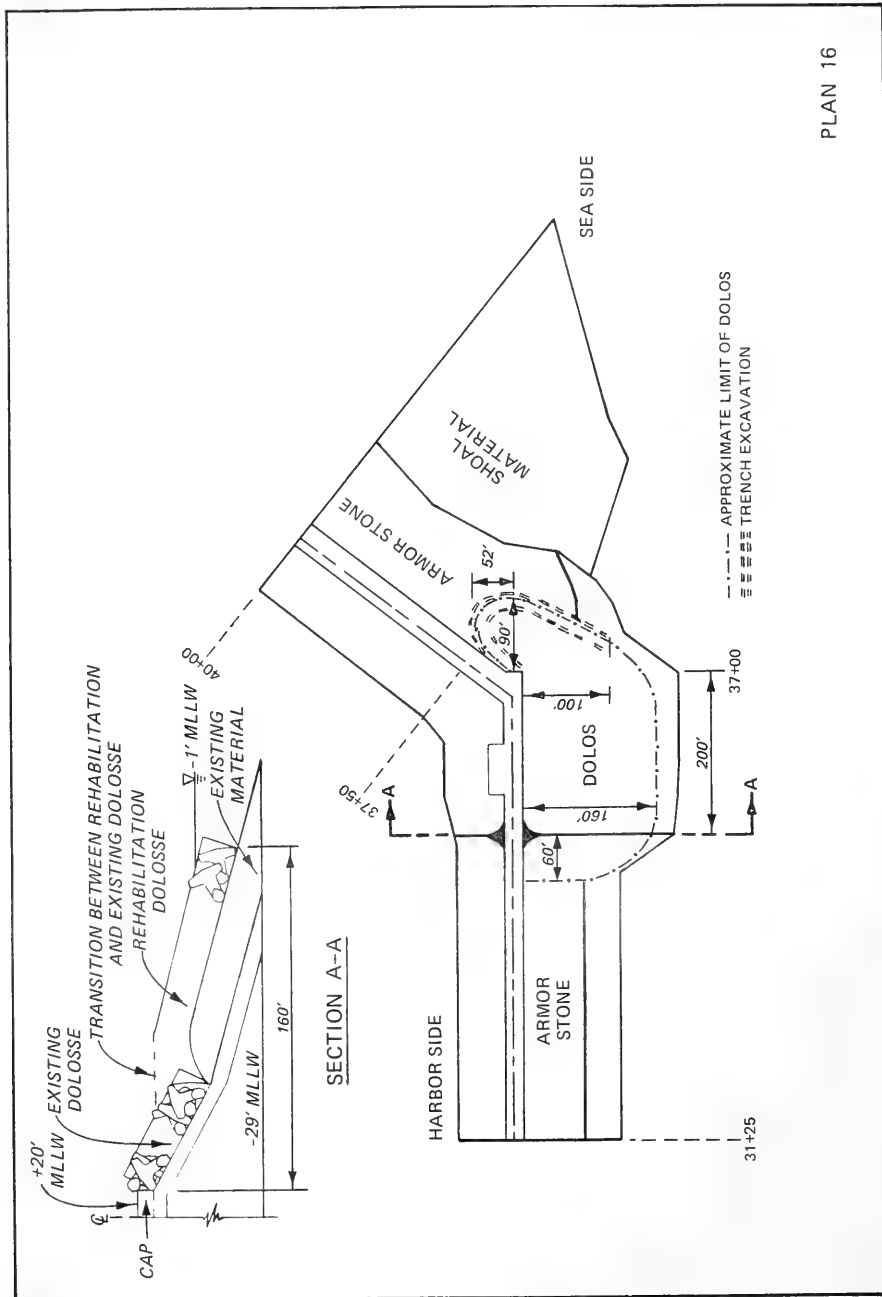


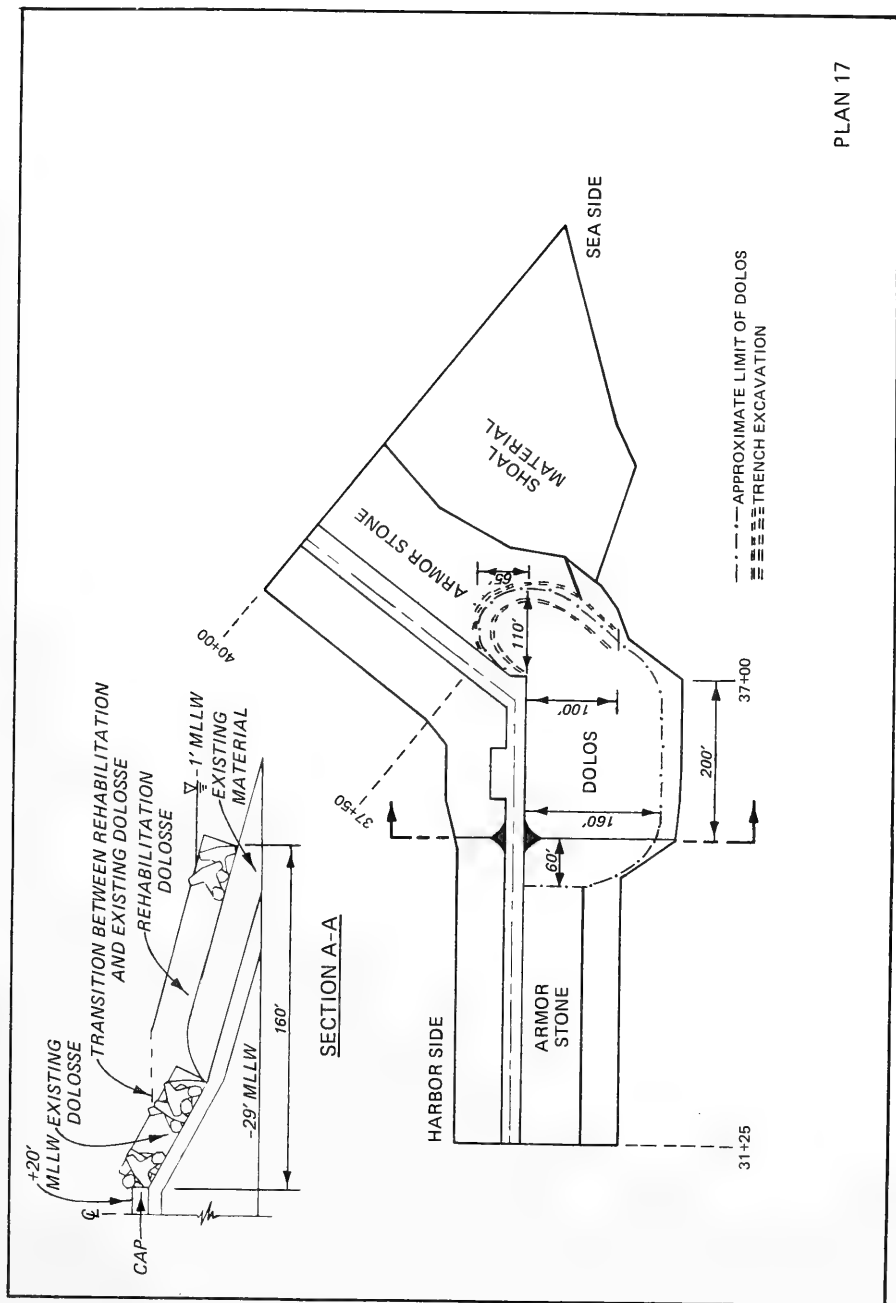


PLAN 11

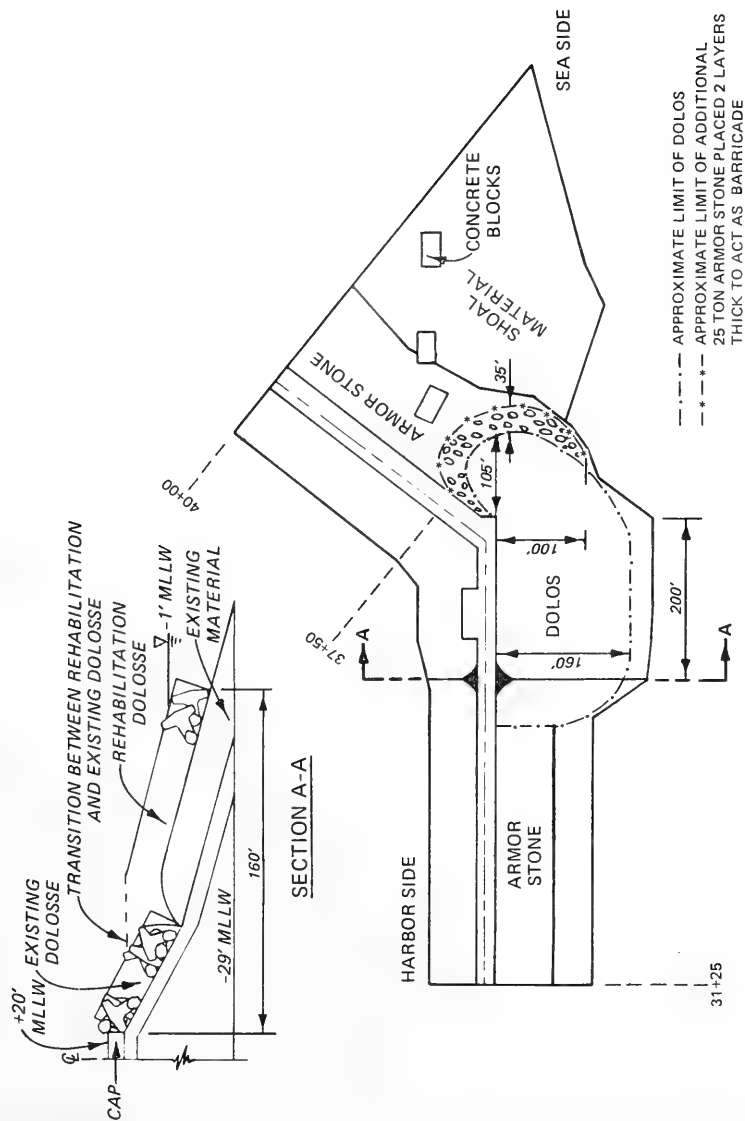




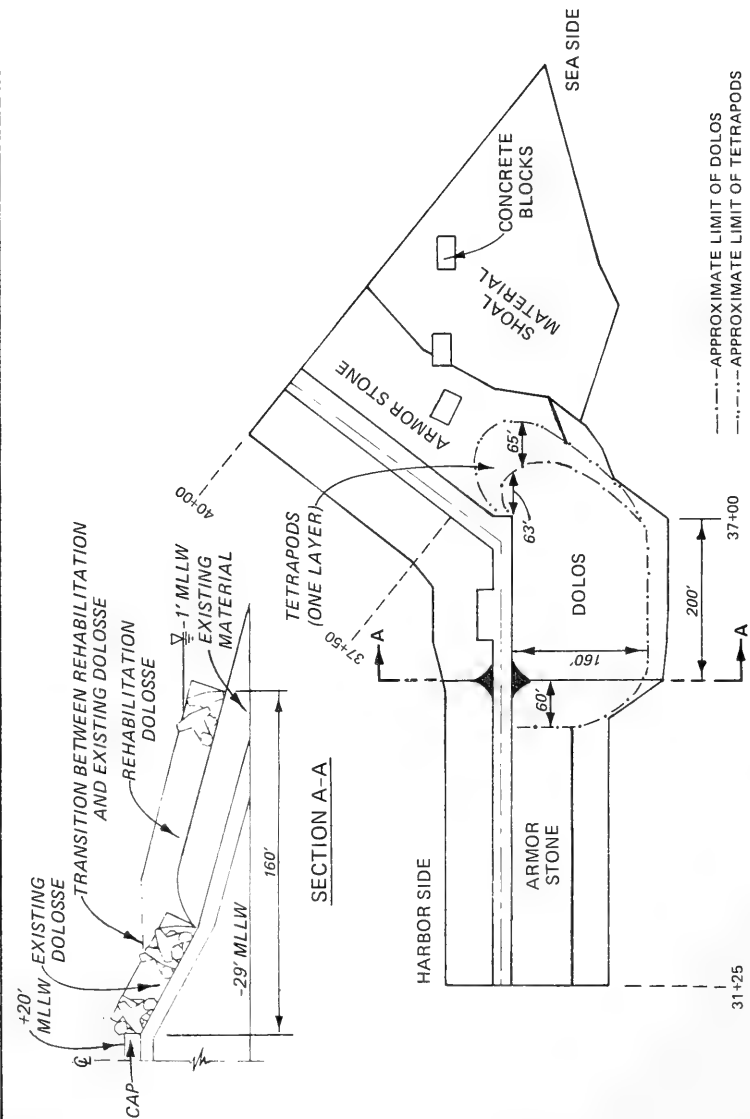


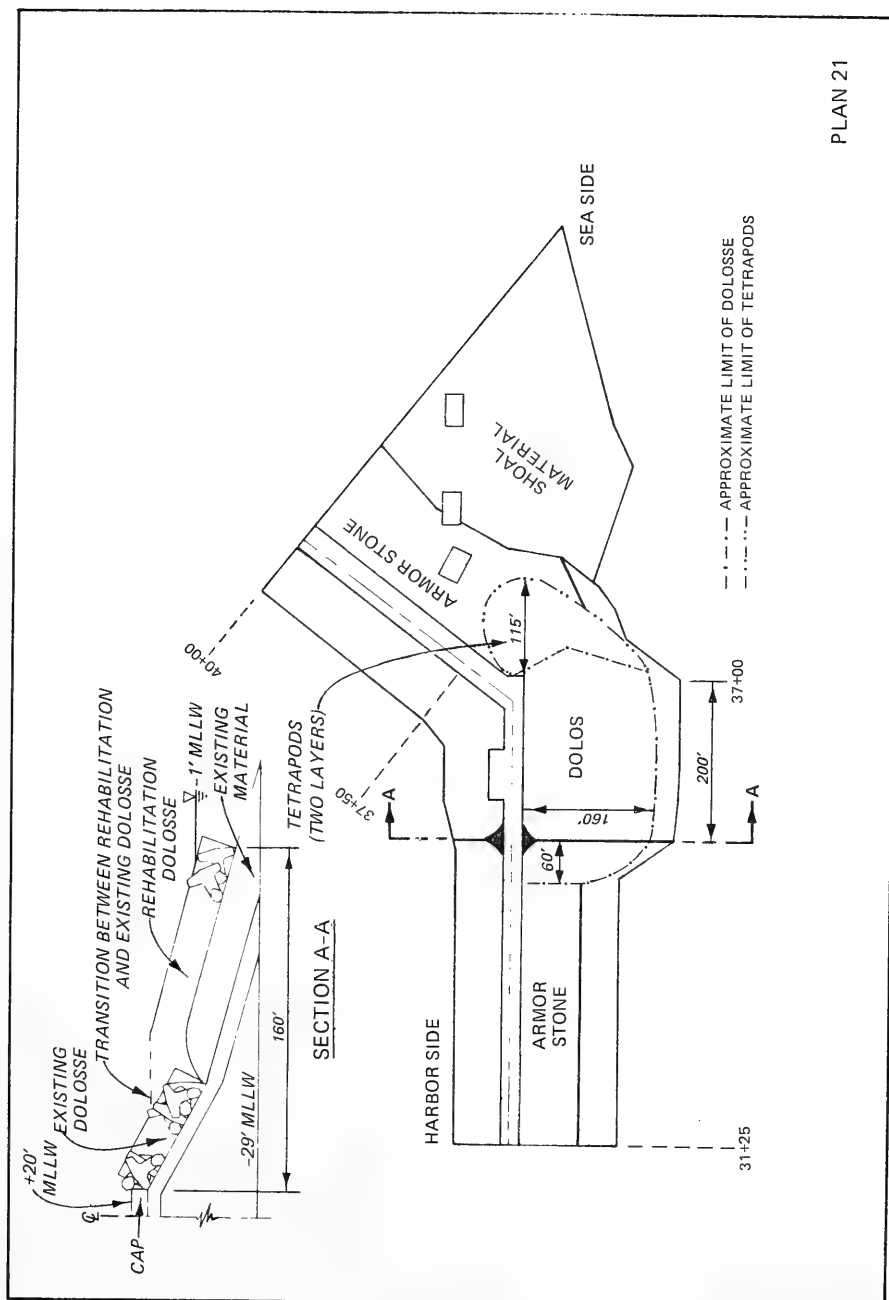


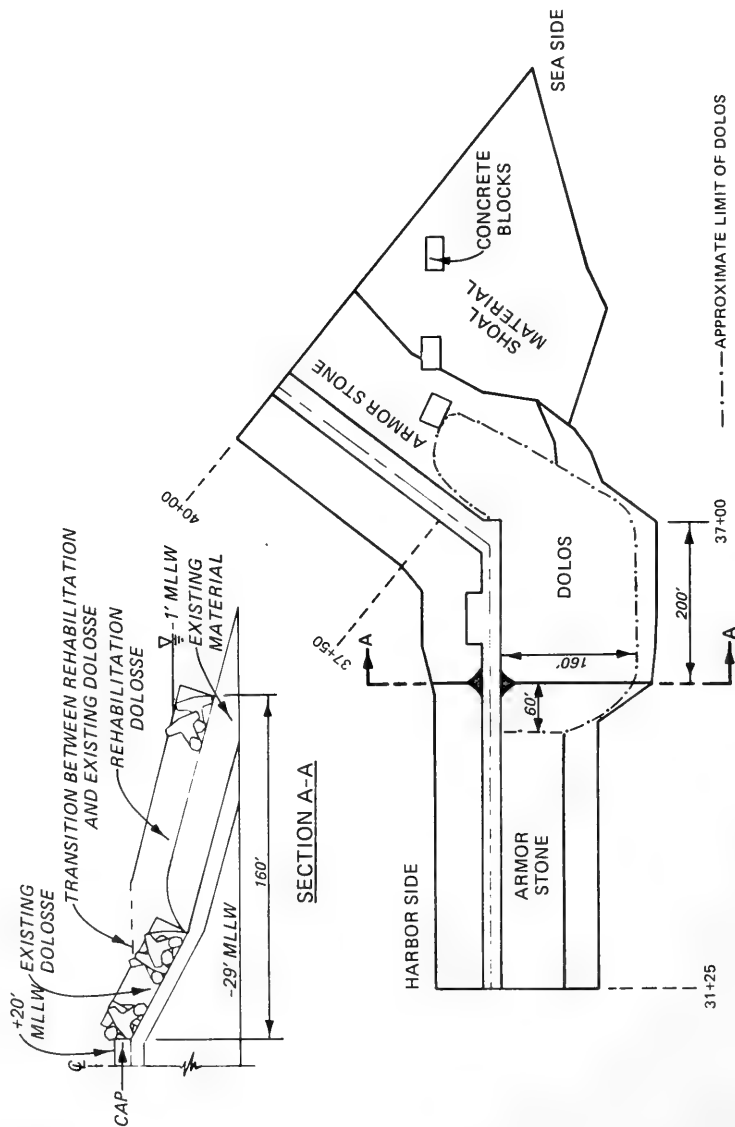


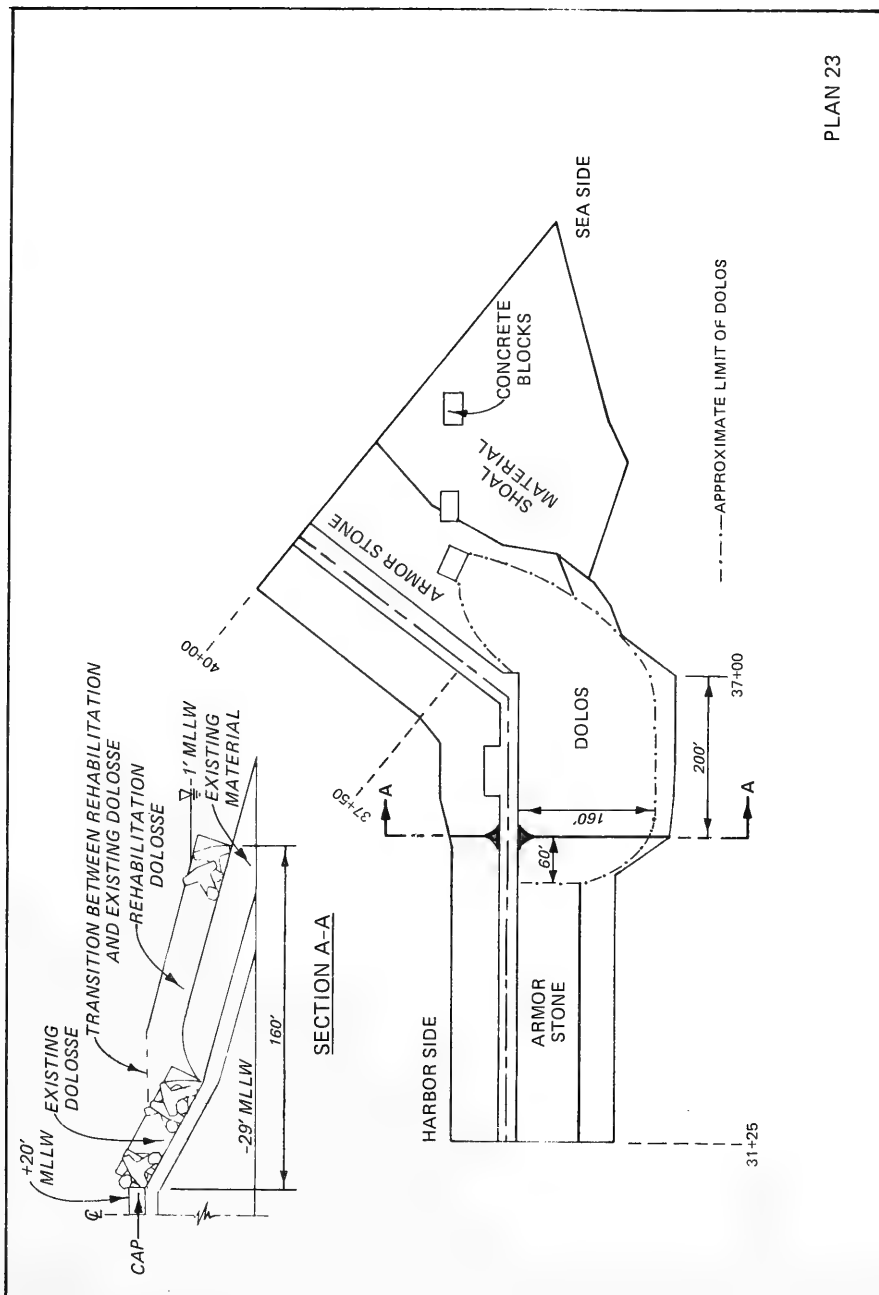


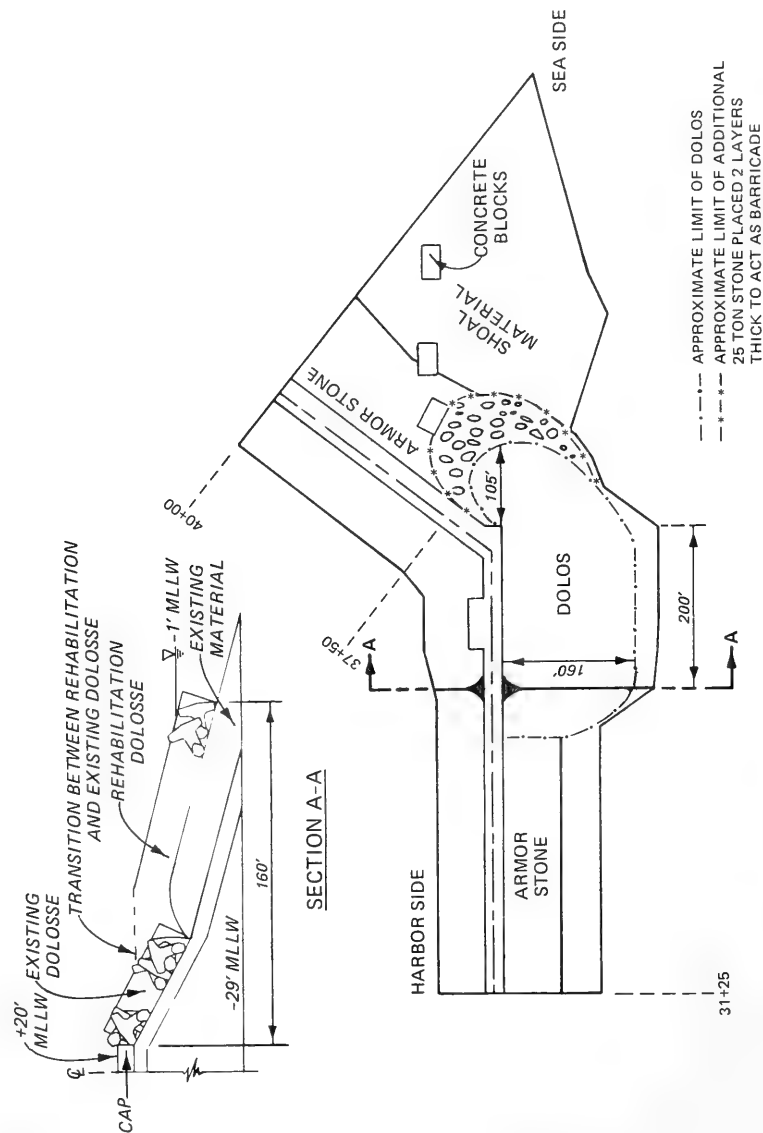
PLAN 19

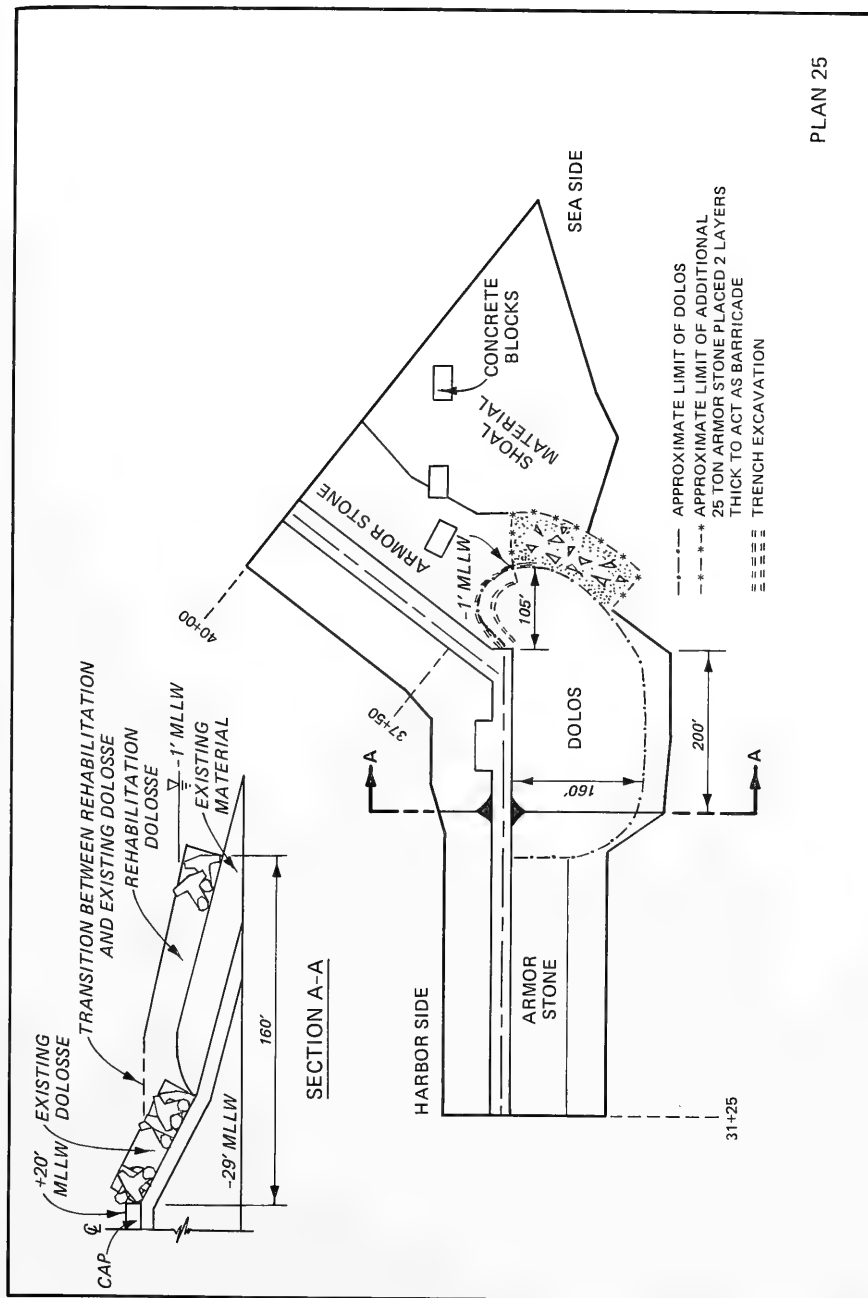


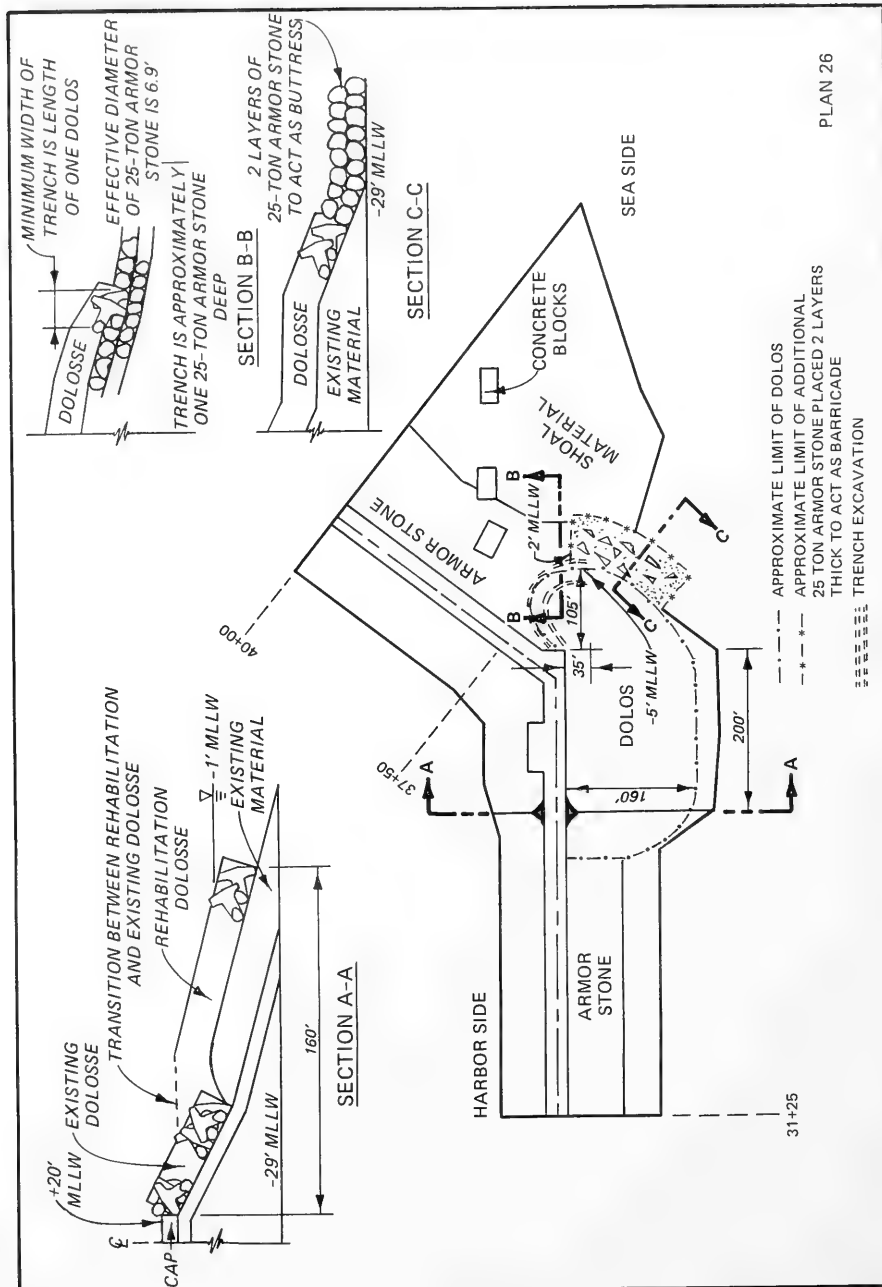


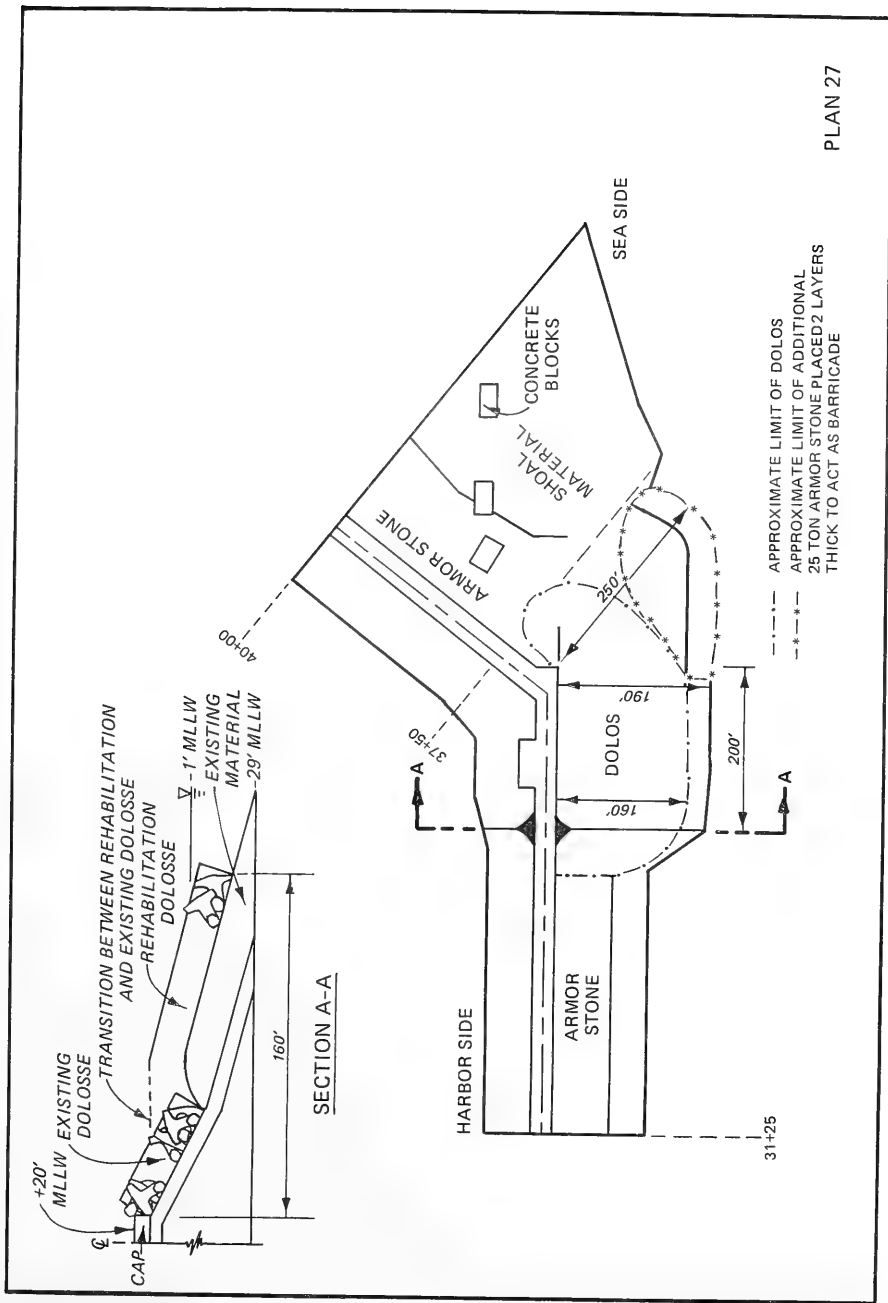




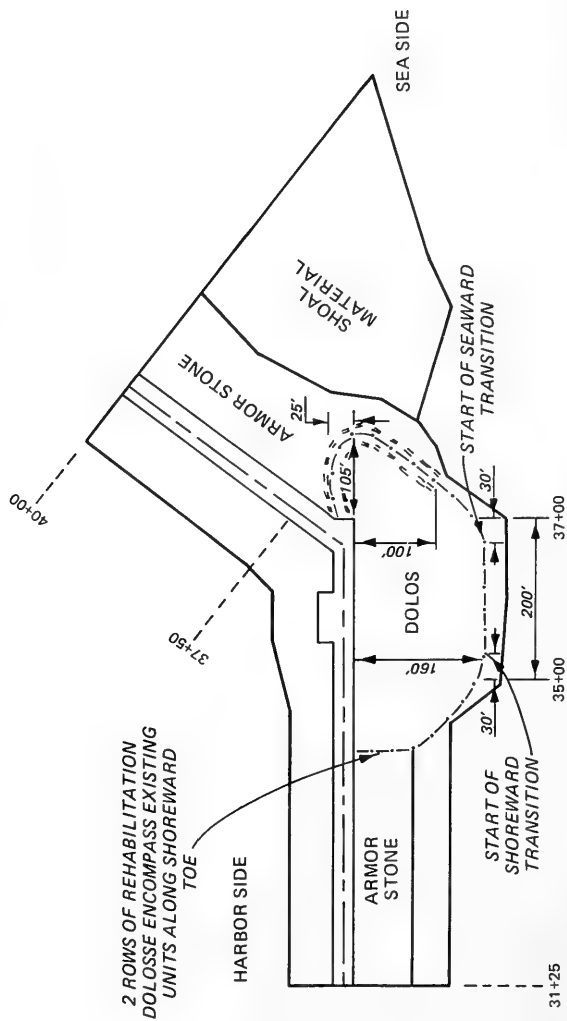




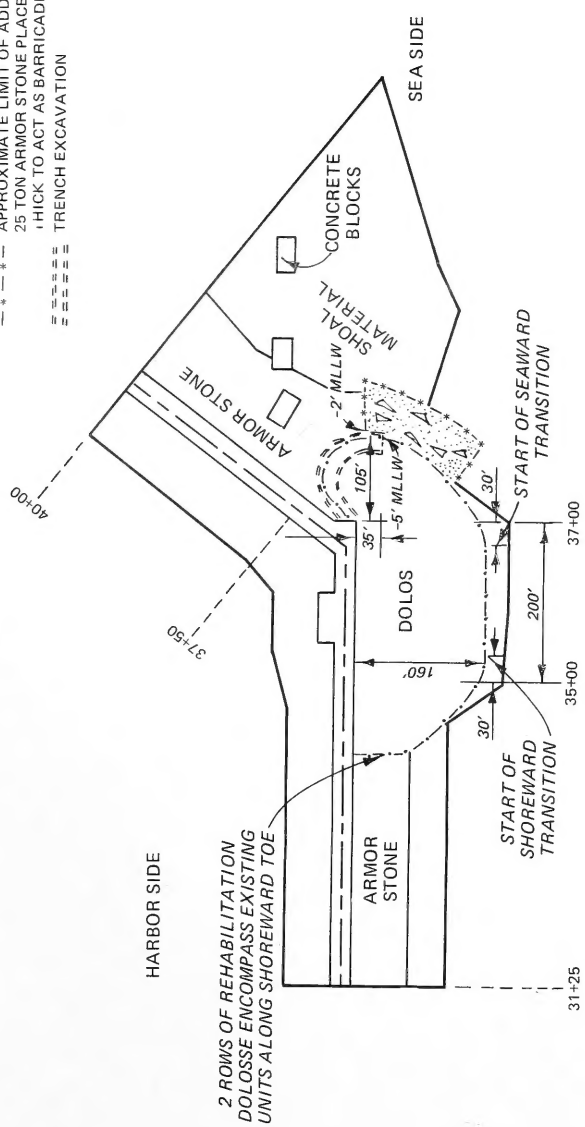




--- APPROXIMATE LIMIT OF DOLOS
 === TRENCH EXCAVATION



- *---*--- APPROXIMATE LIMIT OF DOLOS
- *---*--- APPROXIMATE LIMIT OF ADDITIONAL
25 TON ARMOR STONE PLACED 2 LAYERS
- ===== TRENCH EXCAVATION



PLAN 26 - MODIFIED

